



**AB
GRAD
CON 23**

1
00:00:13,249 --> 00:00:10,750

[Music]

2
00:00:14,810 --> 00:00:13,259

our second keynote speaker of the

3
00:00:16,670 --> 00:00:14,820

conference holds the Chancellor's

4
00:00:19,310 --> 00:00:16,680

distinguished profession professorship

5
00:00:21,590 --> 00:00:19,320

in physics at UCSD he's a theoretical

6
00:00:23,390 --> 00:00:21,600

physicist whose work is wide-ranging and

7
00:00:24,470 --> 00:00:23,400

whose Twitter bio says I'm interested in

8
00:00:26,570 --> 00:00:24,480

everything

9
00:00:27,670 --> 00:00:26,580

before joining UCSD he was at the

10
00:00:29,990 --> 00:00:27,680

University of Illinois at

11
00:00:32,630 --> 00:00:30,000

Urbana-Champaign for over 30 years where

12
00:00:34,430 --> 00:00:32,640

he led the biocomplexity group within

13
00:00:36,889 --> 00:00:34,440

the Carl Roes Institute for genomic

14

00:00:38,810 --> 00:00:36,899

biology and where he both founded and

15

00:00:41,209 --> 00:00:38,820

directed the NASA astrobiology Institute

16

00:00:43,310 --> 00:00:41,219

for Universal biology his research has

17

00:00:45,049 --> 00:00:43,320

been highly multidisciplinary ranging

18

00:00:46,670 --> 00:00:45,059

from condensed matter and hydrodynamics

19

00:00:49,250 --> 00:00:46,680

to the ecology and evolution of living

20

00:00:51,709 --> 00:00:49,260

systems among his many accolades Nigel

21

00:00:53,810 --> 00:00:51,719

received the 2020 leap kadenoff prize

22

00:00:55,670 --> 00:00:53,820

from the American physical Society for

23

00:00:57,410 --> 00:00:55,680

quote profound contributions to the

24

00:00:58,970 --> 00:00:57,420

fields of superconductivity fluid

25

00:01:00,770 --> 00:00:58,980

turbulence and dynamical pattern

26

00:01:02,209 --> 00:01:00,780

formation it's been a pleasure to have

27

00:01:03,950 --> 00:01:02,219

him as a professor and it's a pleasure

28

00:01:10,010 --> 00:01:03,960

to have him with us here today please

29

00:01:13,789 --> 00:01:10,460

birthday

30

00:01:16,130 --> 00:01:13,799

[Applause]

31

00:01:19,910 --> 00:01:16,140

thank you very much for the kind and

32

00:01:21,530 --> 00:01:19,920

invitation to speak at Brad Khan I love

33

00:01:23,690 --> 00:01:21,540

this conference I've sent my students to

34

00:01:24,950 --> 00:01:23,700

it I've been in it before I think it's

35

00:01:27,710 --> 00:01:24,960

absolutely wonderful and I was really

36

00:01:30,469 --> 00:01:27,720

thrilled to see that NASA is still

37

00:01:33,190 --> 00:01:30,479

supporting it and even to uh to uh to

38

00:01:35,810 --> 00:01:33,200

catch up with an old friend and

39

00:01:38,810 --> 00:01:35,820

acquaintance from my days at the NASA

40

00:01:40,550 --> 00:01:38,820

astrobiology Institute hi Mike so I'm

41

00:01:44,870 --> 00:01:40,560

going to talk about something that uh

42

00:01:48,350 --> 00:01:44,880

that by All rights shouldn't exist and I

43

00:01:51,230 --> 00:01:48,360

don't mean life itself and I mean uh

44

00:01:52,550 --> 00:01:51,240

Universal aspects of living systems I'm

45

00:01:55,010 --> 00:01:52,560

a physicist as you heard from the

46

00:01:57,710 --> 00:01:55,020

introduction and so my approach to

47

00:02:00,770 --> 00:01:57,720

anything is is ridiculously as simple

48

00:02:04,010 --> 00:02:00,780

and is almost surely destined for

49

00:02:05,690 --> 00:02:04,020

failure but we try to fail in a in a

50

00:02:08,449 --> 00:02:05,700

grand way and at least see what we can

51
00:02:11,029 --> 00:02:08,459
learn from our attempts to understand uh

52
00:02:12,710 --> 00:02:11,039
the physical principles that govern uh

53
00:02:14,869 --> 00:02:12,720
life so I'm going to talk about

54
00:02:16,910 --> 00:02:14,879
Universal biology the genetic code in

55
00:02:21,770 --> 00:02:16,920
the first billion years of life on Earth

56
00:02:23,690 --> 00:02:21,780
and I have uh collaborators my first

57
00:02:25,790 --> 00:02:23,700
collaborate I want to mention is a Carl

58
00:02:27,710 --> 00:02:25,800
woes who will feature in this story and

59
00:02:30,410 --> 00:02:27,720
many of you may know Carl woes he

60
00:02:32,449 --> 00:02:30,420
discovered the Arca he was a very famous

61
00:02:34,729 --> 00:02:32,459
evolutionary biologist and he was my

62
00:02:37,930 --> 00:02:34,739
mentor when I started doing biology

63
00:02:41,030 --> 00:02:37,940

about 20 years ago

64

00:02:44,150 --> 00:02:41,040

I was one of my graduate students who

65

00:02:46,729 --> 00:02:44,160

did a fantastic work on the generic code

66

00:02:50,509 --> 00:02:46,739

and was in fact also at the University

67

00:02:51,949 --> 00:02:50,519

of Wisconsin where Alex was as a as a

68

00:02:56,089 --> 00:02:51,959

student before

69

00:02:58,309 --> 00:02:56,099

um uh Apache Jaffa is now uh as a in in

70

00:03:01,490 --> 00:02:58,319

the Netherlands and tomato bianchalani

71

00:03:03,290 --> 00:03:01,500

is now working in a genotech here in

72

00:03:05,150 --> 00:03:03,300

California all right so I'm going to

73

00:03:09,170 --> 00:03:05,160

tell you about work that was done uh

74

00:03:10,330 --> 00:03:09,180

over the last uh uh 10 or 10 or 15 years

75

00:03:12,890 --> 00:03:10,340

or so

76
00:03:14,630 --> 00:03:12,900
through the NASA astrobiology Institute

77
00:03:17,030 --> 00:03:14,640
and I hope you're going to find it

78
00:03:20,149 --> 00:03:17,040
interesting if you have any questions

79
00:03:21,530 --> 00:03:20,159
feel free to interrupt during the during

80
00:03:23,809 --> 00:03:21,540
the talk especially if it's a

81
00:03:26,210 --> 00:03:23,819
clarification and I'll be of course be

82
00:03:28,610 --> 00:03:26,220
happy to take questions as as we go

83
00:03:30,649 --> 00:03:28,620
through to the end so the thing I want

84
00:03:32,869 --> 00:03:30,659
to understand is what are the sorts of

85
00:03:35,149 --> 00:03:32,879
evolutionary transitions that life most

86
00:03:39,110 --> 00:03:35,159
inevitably pass through this is part of

87
00:03:42,050 --> 00:03:39,120
a program that the NASA uh discussed in

88
00:03:43,850 --> 00:03:42,060

The Marvelous astrobiology roadmap from

89

00:03:46,130 --> 00:03:43,860

about 15 years ago

90

00:03:48,410 --> 00:03:46,140

trying to understand a universal biology

91

00:03:51,050 --> 00:03:48,420

and look for Universal characteristics

92

00:03:52,729 --> 00:03:51,060

of life and the idea is if we can

93

00:03:55,430 --> 00:03:52,739

understand what features of life on

94

00:03:56,630 --> 00:03:55,440

Earth are not idiosyncratic but actually

95

00:03:58,729 --> 00:03:56,640

just something that we should expect

96

00:04:00,710 --> 00:03:58,739

from another planet and understanding

97

00:04:03,050 --> 00:04:00,720

these processes understanding these

98

00:04:05,809 --> 00:04:03,060

transitions may help us to come up with

99

00:04:08,630 --> 00:04:05,819

uh biosignatures and we'll see that in

100

00:04:11,449 --> 00:04:08,640

fact there are some prospects for that

101
00:04:12,890 --> 00:04:11,459
so I want to understand basically can we

102
00:04:15,710 --> 00:04:12,900
understand some features of Life

103
00:04:17,689 --> 00:04:15,720
Universal features which you may say may

104
00:04:20,150 --> 00:04:17,699
not exist but we'll see we'll see it's

105
00:04:22,189 --> 00:04:20,160
the country and can we understand from

106
00:04:23,930 --> 00:04:22,199
general dynamical principles without

107
00:04:25,490 --> 00:04:23,940
necessarily having to worry about all

108
00:04:27,830 --> 00:04:25,500
the chemical details

109
00:04:30,170 --> 00:04:27,840
so I'm going to talk about two things in

110
00:04:32,390 --> 00:04:30,180
this talk I'm going to talk about uh the

111
00:04:35,510 --> 00:04:32,400
canonical genetic code and that's going

112
00:04:37,430 --> 00:04:35,520
to be most the most of my talk I will

113
00:04:39,950 --> 00:04:37,440

talk about biological homochirality

114

00:04:42,409 --> 00:04:39,960

because it is important as a as a bio

115

00:04:45,530 --> 00:04:42,419

signature it's been assumed to be a

116

00:04:47,810 --> 00:04:45,540

biosignature but um but actually we'll

117

00:04:49,810 --> 00:04:47,820

see in this talk that actually there are

118

00:04:52,850 --> 00:04:49,820

dynamical reasons for thinking that

119

00:04:55,010 --> 00:04:52,860

homochirality isn't inevitable outcome of

120

00:04:57,590 --> 00:04:55,020

living systems

121

00:04:59,570 --> 00:04:57,600

so I want to first start off though by

122

00:05:02,270 --> 00:04:59,580

talking about are there any universal

123

00:05:04,430 --> 00:05:02,280

features in biology and and how should

124

00:05:05,990 --> 00:05:04,440

we think about them so I'm a physicist

125

00:05:08,330 --> 00:05:06,000

so I start off by asking is there

126

00:05:11,570 --> 00:05:08,340

universality in physics so here's an

127

00:05:14,330 --> 00:05:11,580

example this is thermal conductivity or

128

00:05:16,969 --> 00:05:14,340

various uh glassy materials this is raw

129

00:05:19,070 --> 00:05:16,979

data and then when we process it in a

130

00:05:21,590 --> 00:05:19,080

certain way the data from different

131

00:05:23,330 --> 00:05:21,600

materials all collapse onto one uh

132

00:05:25,129 --> 00:05:23,340

Universal curve except for this regime

133

00:05:26,810 --> 00:05:25,139

over here and so that's something that

134

00:05:29,409 --> 00:05:26,820

we try to understand if we want to

135

00:05:31,670 --> 00:05:29,419

understand glassly and glassy materials

136

00:05:34,550 --> 00:05:31,680

here's another example which is a much

137

00:05:37,070 --> 00:05:34,560

better one this example is looking at

138

00:05:39,170 --> 00:05:37,080

the magnetic field or the magnetization

139

00:05:43,070 --> 00:05:39,180

in a magnet exposed to an external

140

00:05:44,870 --> 00:05:43,080

magnetic field H at temperature t as you

141

00:05:46,610 --> 00:05:44,880

go through the ferromagnetic phase

142

00:05:48,890 --> 00:05:46,620

transition the transition that makes

143

00:05:50,950 --> 00:05:48,900

stuff be magnetic at low temperatures

144

00:05:54,170 --> 00:05:50,960

and not magnetic at high temperatures

145

00:05:56,510 --> 00:05:54,180

and you the data you take from a

146

00:05:59,510 --> 00:05:56,520

different external magnetic fields

147

00:06:01,370 --> 00:05:59,520

different u_h temperatures and then if

148

00:06:03,469 --> 00:06:01,380

you process the data in the right way

149

00:06:05,210 --> 00:06:03,479

all these data from five different

150

00:06:07,129 --> 00:06:05,220

materials none of which are look

151

00:06:10,430 --> 00:06:07,139

anything alike all fall onto one

152

00:06:12,770 --> 00:06:10,440

universal curve and the prediction for

153

00:06:15,650 --> 00:06:12,780

that curve is the solid line which goes

154

00:06:18,230 --> 00:06:15,660

embarrassingly close to all the data and

155

00:06:21,350 --> 00:06:18,240

it has no adjustable parameters

156

00:06:23,809 --> 00:06:21,360

so that's another example of of scaling

157

00:06:25,129 --> 00:06:23,819

and universality in physics and you

158

00:06:27,230 --> 00:06:25,139

might say well this is this is really

159

00:06:29,450 --> 00:06:27,240

great because what did the physicists do

160

00:06:31,730 --> 00:06:29,460

they made a model of a magnetic system

161

00:06:33,350 --> 00:06:31,740

and then they took that model worked out

162

00:06:35,450 --> 00:06:33,360

its consequences did some calculations

163

00:06:37,189 --> 00:06:35,460

and then showed that it gave a precise

164

00:06:39,409 --> 00:06:37,199

prediction in agreement with experiments

165

00:06:41,270 --> 00:06:39,419

that's what physicists usually do in

166

00:06:42,650 --> 00:06:41,280

fact it's nothing like that at all but

167

00:06:44,870 --> 00:06:42,660

actually it is it's a model of a model

168

00:06:47,510 --> 00:06:44,880

of a model of a model of a model and

169

00:06:49,249 --> 00:06:47,520

that that does all the work the first

170

00:06:51,050 --> 00:06:49,259

model is a model of quantum chemistry

171

00:06:52,909 --> 00:06:51,060

then there's a model of electronic

172

00:06:54,770 --> 00:06:52,919

structure then there's a model of the

173

00:06:57,290 --> 00:06:54,780

dipole moment on the electronic spins

174

00:06:59,330 --> 00:06:57,300

that uses quantum mechanics and then you

175

00:07:01,309 --> 00:06:59,340

say well quantum mechanics is too hard

176

00:07:03,110 --> 00:07:01,319

so let's get rid of quantum mechanics

177

00:07:04,610 --> 00:07:03,120

and then you have a classical and you

178

00:07:06,830 --> 00:07:04,620

still can't do it and only make some

179

00:07:09,890 --> 00:07:06,840

sort of approximation that position to

180

00:07:12,170 --> 00:07:09,900

call Landau Theory and then you you get

181

00:07:13,909 --> 00:07:12,180

the results that I showed you

182

00:07:16,070 --> 00:07:13,919

and the thing you want I want you to

183

00:07:17,870 --> 00:07:16,080

understand the reason why I'm uh

184

00:07:20,450 --> 00:07:17,880

tormenting you with this physics stuff

185

00:07:23,570 --> 00:07:20,460

is because every step along the way here

186

00:07:25,370 --> 00:07:23,580

is a non-systematic approximation you

187

00:07:27,950 --> 00:07:25,380

cannot justify these approximations

188

00:07:29,749 --> 00:07:27,960

starting from first principles from the

189

00:07:32,990 --> 00:07:29,759

Schrodinger equation or whatever else it

190

00:07:36,230 --> 00:07:33,000

is so the point is here is an example of

191

00:07:39,110 --> 00:07:36,240

how a ludicrously simple model that has

192

00:07:42,230 --> 00:07:39,120

no right to actually be able to describe

193

00:07:44,390 --> 00:07:42,240

reality actually describes it precisely

194

00:07:45,950 --> 00:07:44,400

and we know in this case why it works it

195

00:07:47,629 --> 00:07:45,960

works in this case because of a thing

196

00:07:49,490 --> 00:07:47,639

called renormalization group Theory

197

00:07:51,950 --> 00:07:49,500

which Ken Wilson won the Nobel Prize for

198

00:07:53,990 --> 00:07:51,960

inventing in the 1980s and so we

199

00:07:56,330 --> 00:07:54,000

understand how all these approximations

200

00:07:57,710 --> 00:07:56,340

that we made throw away stuff that

201
00:07:59,689 --> 00:07:57,720
really doesn't matter for the thing that

202
00:08:02,089 --> 00:07:59,699
we were trying to calculate

203
00:08:04,610 --> 00:08:02,099
so that's the uh so that that tells you

204
00:08:07,490 --> 00:08:04,620
that it is not impossible to make

205
00:08:10,129 --> 00:08:07,500
ludicrously simple models and still have

206
00:08:12,290 --> 00:08:10,139
some understanding of how the system

207
00:08:14,210 --> 00:08:12,300
actually behaves

208
00:08:17,150 --> 00:08:14,220
okay so but we're going to of course

209
00:08:20,390 --> 00:08:17,160
apply that type of modeling philosophy

210
00:08:23,629 --> 00:08:20,400
uh to biology but first of all let's ask

211
00:08:25,189 --> 00:08:23,639
another question so for me as a

212
00:08:28,010 --> 00:08:25,199
physicist I want to know do we learn new

213
00:08:29,809 --> 00:08:28,020

physics when we study biology or is it

214

00:08:32,389 --> 00:08:29,819

just insanely complicated Material

215

00:08:34,370 --> 00:08:32,399

Science are they Universal phenomena do

216

00:08:35,750 --> 00:08:34,380

they reveal anything important and what

217

00:08:37,909 --> 00:08:35,760

do we miss by not understanding

218

00:08:38,990 --> 00:08:37,919

Universal phenomena okay I'm going to

219

00:08:40,250 --> 00:08:39,000

show you that the high Universal

220

00:08:42,290 --> 00:08:40,260

phenomena some of you will be very

221

00:08:44,449 --> 00:08:42,300

surprised at the examples I'm going to

222

00:08:46,130 --> 00:08:44,459

show you I'm also going to show you that

223

00:08:48,110 --> 00:08:46,140

if we don't understand these Universal

224

00:08:50,630 --> 00:08:48,120

phenomena not only can we not understand

225

00:08:52,370 --> 00:08:50,640

how life started at all and how it

226

00:08:55,730 --> 00:08:52,380

evolved we certainly can't understand

227

00:08:58,190 --> 00:08:55,740

how to do things like respond to a

228

00:09:01,310 --> 00:08:58,200

pandemic or deal with antibiotic

229

00:09:03,769 --> 00:09:01,320

resistance or herbicide doesn't or

230

00:09:05,870 --> 00:09:03,779

Cancer all of these things depend on

231

00:09:07,970 --> 00:09:05,880

understanding Evolution and these

232

00:09:09,949 --> 00:09:07,980

Universal properties

233

00:09:12,710 --> 00:09:09,959

okay so let's talk about Universal

234

00:09:14,750 --> 00:09:12,720

biology so so uh let me give you an

235

00:09:17,329 --> 00:09:14,760

example here

236

00:09:20,090 --> 00:09:17,339

so this was uh this was a headline on

237

00:09:22,430 --> 00:09:20,100

the NASA website at some point uh 2013

238

00:09:24,889 --> 00:09:22,440

about 10 years ago mystery of the

239

00:09:27,590 --> 00:09:24,899

missing waves on Titan so basically

240

00:09:30,889 --> 00:09:27,600

people knew that from looking at the uh

241

00:09:33,590 --> 00:09:30,899

at uh the flow mechanics and and the

242

00:09:37,370 --> 00:09:33,600

atmosphere of Titan that there should be

243

00:09:40,009 --> 00:09:37,380

uh waves on on the surface of Titan

244

00:09:41,570 --> 00:09:40,019

um and uh and uh so there was a mystery

245

00:09:44,389 --> 00:09:41,580

they weren't there we couldn't see them

246

00:09:47,329 --> 00:09:44,399

nobody knew why and then about a year

247

00:09:51,530 --> 00:09:47,339

later uh Cassini Spies The wind-rippled

248

00:09:53,269 --> 00:09:51,540

Waves uh on Titan so so suddenly sign of

249

00:09:55,790 --> 00:09:53,279

relief thank goodness you you can sleep

250

00:09:58,550 --> 00:09:55,800

at night we found the waves on the

251
00:10:01,670 --> 00:09:58,560
surface of the oceans of Titan okay so

252
00:10:04,730 --> 00:10:01,680
that's a real real headline okay here's

253
00:10:06,710 --> 00:10:04,740
what here's one that you have Okay so I

254
00:10:08,210 --> 00:10:06,720
just forget I forgot this we know the

255
00:10:09,769 --> 00:10:08,220
waves on the ocean of Titan are missing

256
00:10:11,810 --> 00:10:09,779
because there's a general theory of

257
00:10:13,190 --> 00:10:11,820
two-phase fluid flow interfaces but

258
00:10:15,350 --> 00:10:13,200
predict waves and the dispersion

259
00:10:17,990 --> 00:10:15,360
characteristics so we knew what to look

260
00:10:19,430 --> 00:10:18,000
for okay here's a headline that you

261
00:10:22,310 --> 00:10:19,440
didn't see

262
00:10:23,870 --> 00:10:22,320
mystery of the missing life on Titan and

263
00:10:25,970 --> 00:10:23,880

then definitely not this one Cassini

264

00:10:28,550 --> 00:10:25,980

Spies The long-sort Life on Titan okay

265

00:10:30,769 --> 00:10:28,560

anybody seen that headline it never

266

00:10:33,230 --> 00:10:30,779

occurred okay and it's a joke right

267

00:10:34,190 --> 00:10:33,240

because it's a joke because we don't

268

00:10:36,350 --> 00:10:34,200

know if there's a missing life because

269

00:10:37,490 --> 00:10:36,360

we don't have a theory that predicts the

270

00:10:39,769 --> 00:10:37,500

existence of Life as a physical

271

00:10:41,930 --> 00:10:39,779

phenomena so that's the first thing why

272

00:10:43,430 --> 00:10:41,940

does life as a phenomenon exist and we

273

00:10:45,290 --> 00:10:43,440

certainly don't understand what sort of

274

00:10:46,550 --> 00:10:45,300

Life can exist in different uh

275

00:10:48,350 --> 00:10:46,560

environments

276
00:10:53,990 --> 00:10:48,360
so so

277
00:10:55,730 --> 00:10:54,000
back to Cassini Cassini May indeed have

278
00:10:57,410 --> 00:10:55,740
actually seen life

279
00:10:59,650 --> 00:10:57,420
but not on Titan

280
00:11:02,150 --> 00:10:59,660
it may have seen life

281
00:11:04,310 --> 00:11:02,160
okay so how many people here know about

282
00:11:07,250 --> 00:11:04,320
Enceladus

283
00:11:08,990 --> 00:11:07,260
great a lot more a lot more people than

284
00:11:11,870 --> 00:11:09,000
word as a typical physics colloquium

285
00:11:15,170 --> 00:11:11,880
right so so good so so as you know

286
00:11:17,150 --> 00:11:15,180
insolidos is a is an isolated World

287
00:11:20,769 --> 00:11:17,160
orbiting Saturn

288
00:11:23,329 --> 00:11:20,779

um it has a global ocean of liquid water

289

00:11:25,730 --> 00:11:23,339

underneath the ice and we know that

290

00:11:27,530 --> 00:11:25,740

because we can see how it wobbles and

291

00:11:29,170 --> 00:11:27,540

because of the way it wobbles we can

292

00:11:32,030 --> 00:11:29,180

detect there must be life underneath

293

00:11:34,970 --> 00:11:32,040

there must be water underneath and it

294

00:11:37,310 --> 00:11:34,980

also obligingly has a crack in the ice

295

00:11:38,990 --> 00:11:37,320

lots of cracks and so water squirts out

296

00:11:40,610 --> 00:11:39,000

through the cracks and so you've got a

297

00:11:42,710 --> 00:11:40,620

fountain a huge fountain and you can fly

298

00:11:45,470 --> 00:11:42,720

satellites through the fountain and you

299

00:11:46,670 --> 00:11:45,480

can look at the water that you uh that

300

00:11:49,370 --> 00:11:46,680

you pick up

301
00:11:51,470 --> 00:11:49,380
and that water you can analyze it's

302
00:11:53,329 --> 00:11:51,480
chemistry and its chemistry looks very

303
00:11:55,610 --> 00:11:53,339
similar to what we might see as an

304
00:11:58,910 --> 00:11:55,620
alkaline hydrothermal vent here on Earth

305
00:12:01,670 --> 00:11:58,920
so we Cassini wasn't instrumented for

306
00:12:04,550 --> 00:12:01,680
looking at life but we may have seen

307
00:12:07,069 --> 00:12:04,560
some signatures of life through that

308
00:12:12,530 --> 00:12:09,769
so what is what is also biology well

309
00:12:14,389 --> 00:12:12,540
Universal biology is the idea that we

310
00:12:16,550 --> 00:12:14,399
are interested in general principles and

311
00:12:18,829 --> 00:12:16,560
not specific carbon chemistry details

312
00:12:20,449 --> 00:12:18,839
and so we want to develop a theory of

313
00:12:22,730 --> 00:12:20,459

universal biology divorced from

314

00:12:25,130 --> 00:12:22,740

idiosyncratic details of the actual

315

00:12:27,970 --> 00:12:25,140

chemistry and the and the geological

316

00:12:31,250 --> 00:12:27,980

context and so on and this will involve

317

00:12:33,710 --> 00:12:31,260

abstractions and and we use abstractions

318

00:12:36,530 --> 00:12:33,720

all the time in in biology and we'll

319

00:12:39,170 --> 00:12:36,540

talk about one of those in a minute

320

00:12:40,910 --> 00:12:39,180

so this slide is pretty much all we know

321

00:12:43,790 --> 00:12:40,920

about Universal biology

322

00:12:46,910 --> 00:12:43,800

so are you looking at it carefully

323

00:12:49,190 --> 00:12:46,920

there's not much there so let's talk

324

00:12:51,530 --> 00:12:49,200

instead about something where we do have

325

00:12:52,730 --> 00:12:51,540

an understanding and that is universal

326

00:12:54,889 --> 00:12:52,740

computation

327

00:12:57,230 --> 00:12:54,899

so I want to tell you now about what we

328

00:12:59,829 --> 00:12:57,240

what a universal biology would look like

329

00:13:03,230 --> 00:12:59,839

if we could do it and we use as a Model

330

00:13:04,610 --> 00:13:03,240

A computer so here is a picture of my

331

00:13:05,690 --> 00:13:04,620

computer or something close to my

332

00:13:10,970 --> 00:13:05,700

computer

333

00:13:12,530 --> 00:13:10,980

see a few hundred miles up the road at

334

00:13:15,170 --> 00:13:12,540

the Museum of computation in Mountain

335

00:13:17,269 --> 00:13:15,180

View or in my case I saw it at the

336

00:13:19,069 --> 00:13:17,279

science museum in London this is a

337

00:13:21,710 --> 00:13:19,079

computer made out of COG wheels and

338

00:13:24,470 --> 00:13:21,720

springs designed and partially built by

339

00:13:28,490 --> 00:13:24,480

George Babbage in the 1900s it is the

340

00:13:30,590 --> 00:13:28,500

authentic steampunk artifact

341

00:13:33,590 --> 00:13:30,600

these two things are the same

342

00:13:36,530 --> 00:13:33,600

they're the same algorithmically this

343

00:13:38,930 --> 00:13:36,540

thing over here the left hand side is a

344

00:13:41,629 --> 00:13:38,940

computer and you know that it's uh not

345

00:13:43,850 --> 00:13:41,639

uh just a shiny chunk of glass plastic

346

00:13:45,050 --> 00:13:43,860

and silicon it's actually a universal

347

00:13:47,210 --> 00:13:45,060

turing machine

348

00:13:48,889 --> 00:13:47,220

the thing on the right is also a turing

349

00:13:51,050 --> 00:13:48,899

machine because it has conditional

350

00:13:52,550 --> 00:13:51,060

branching in its instruction set and so

351
00:13:55,490 --> 00:13:52,560
it can be shown that it can be mapped

352
00:13:56,769 --> 00:13:55,500
onto a universal turing machine so in

353
00:13:58,970 --> 00:13:56,779
fact the two things are the same

354
00:14:00,530 --> 00:13:58,980
although one of them is at many times

355
00:14:02,090 --> 00:14:00,540
faster than the other

356
00:14:04,430 --> 00:14:02,100
so the turing machine with an online

357
00:14:06,650 --> 00:14:04,440
architecture is really what a computer

358
00:14:10,009 --> 00:14:06,660
is and we have Hardware to instantiate

359
00:14:12,590 --> 00:14:10,019
uh that uh that algorithm so the medium

360
00:14:14,930 --> 00:14:12,600
is not the message here is John Von

361
00:14:16,970 --> 00:14:14,940
Neumann standing in front of another

362
00:14:19,610 --> 00:14:16,980
computer that he built at The Institute

363
00:14:21,470 --> 00:14:19,620

for advanced study in the 1950s in this

364

00:14:24,710 --> 00:14:21,480

computer it's built out of thermionic

365

00:14:27,110 --> 00:14:24,720

valves it's built out of relays and

366

00:14:28,910 --> 00:14:27,120

switches and so neither this nor this

367

00:14:31,910 --> 00:14:28,920

we're seeing here the evolution of

368

00:14:33,710 --> 00:14:31,920

computational Hardware but in all of

369

00:14:35,210 --> 00:14:33,720

these machines they all do the same

370

00:14:37,250 --> 00:14:35,220

thing they're all Universal Turing

371

00:14:39,290 --> 00:14:37,260

machines and so we're looking at life we

372

00:14:42,050 --> 00:14:39,300

should be thinking about life as making

373

00:14:45,050 --> 00:14:42,060

a progression as you see over here but

374

00:14:46,550 --> 00:14:45,060

executing the same sort of algorithmic

375

00:14:49,250 --> 00:14:46,560

processes

376

00:14:51,829 --> 00:14:49,260

now these are new physical laws in in

377

00:14:53,269 --> 00:14:51,839

biology well uh Schrodinger and Dell

378

00:14:55,610 --> 00:14:53,279

Brooke were the first physicists to work

379

00:14:57,650 --> 00:14:55,620

in biology and their partial motivation

380

00:14:59,389 --> 00:14:57,660

was to find new physical laws they were

381

00:15:02,030 --> 00:14:59,399

thinking about quantum mechanics in the

382

00:15:03,590 --> 00:15:02,040

1930s as they might see some deviations

383

00:15:07,730 --> 00:15:03,600

from quantum mechanics or something like

384

00:15:09,110 --> 00:15:07,740

that but today we not many people well

385

00:15:12,410 --> 00:15:09,120

some people think that could be still

386

00:15:14,329 --> 00:15:12,420

true but most of us think that uh

387

00:15:16,189 --> 00:15:14,339

big question is trying to understand

388

00:15:19,129 --> 00:15:16,199

emergence and the existence of life

389

00:15:22,210 --> 00:15:19,139

itself how is it that matter at

390

00:15:25,189 --> 00:15:22,220

molecules and atoms are self-organize

391

00:15:27,470 --> 00:15:25,199

hierarchically create replicating and

392

00:15:30,170 --> 00:15:27,480

evolvable structures we don't have a

393

00:15:32,389 --> 00:15:30,180

clue about how that happens how do

394

00:15:33,949 --> 00:15:32,399

molecules come to life so if you want to

395

00:15:36,050 --> 00:15:33,959

understand biology in the same way that

396

00:15:38,329 --> 00:15:36,060

we understand physical phenomena we need

397

00:15:40,970 --> 00:15:38,339

to understand the existence and not just

398

00:15:42,530 --> 00:15:40,980

the specific realization of of living

399

00:15:44,269 --> 00:15:42,540

systems

400

00:15:46,910 --> 00:15:44,279

and I'm going to take the perspective

401
00:15:49,129 --> 00:15:46,920
here that living systems are dynamical

402
00:15:50,210 --> 00:15:49,139
systems that are able to reprogram

403
00:15:52,009 --> 00:15:50,220
themselves

404
00:15:54,590 --> 00:15:52,019
so let's think about that

405
00:15:56,870 --> 00:15:54,600
so here is the uh here is the fortune

406
00:15:59,090 --> 00:15:56,880
cookie the program is the data the data

407
00:16:01,970 --> 00:15:59,100
is the program okay this is Niels

408
00:16:04,370 --> 00:16:01,980
barricelli who was uh the first person

409
00:16:06,889 --> 00:16:04,380
to write a computer virus he was working

410
00:16:09,050 --> 00:16:06,899
at The Institute for advanced study and

411
00:16:10,910 --> 00:16:09,060
in the day while John Von Neumann was

412
00:16:13,730 --> 00:16:10,920
using the computer one of the first

413
00:16:16,310 --> 00:16:13,740

computers to uh solve the equations of

414

00:16:18,889 --> 00:16:16,320

hydrodynamics to design uh hydrogen

415

00:16:21,430 --> 00:16:18,899

bombs uh Niels banacelli went in at

416

00:16:24,110 --> 00:16:21,440

night and made a

417

00:16:26,990 --> 00:16:24,120

computer viruses and then had them

418

00:16:29,689 --> 00:16:27,000

compete and and evolve with each other

419

00:16:32,269 --> 00:16:29,699

inside a fixed ecosystem which was the

420

00:16:34,670 --> 00:16:32,279

memory of the of the computer

421

00:16:37,910 --> 00:16:34,680

and here he understood what he was

422

00:16:40,090 --> 00:16:37,920

seeing here was uh was actually being of

423

00:16:43,189 --> 00:16:40,100

the phenomena that we see in evolving

424

00:16:45,650 --> 00:16:43,199

evolvable ecosystems

425

00:16:47,749 --> 00:16:45,660

so what do self-programming systems uh

426

00:16:50,389 --> 00:16:47,759

can do well living systems have the

427

00:16:52,910 --> 00:16:50,399

capacity to evolve and evolving systems

428

00:16:55,249 --> 00:16:52,920

can reprogram themselves so they're able

429

00:16:57,889 --> 00:16:55,259

to respond to perturbations by creating

430

00:17:00,350 --> 00:16:57,899

new functionality that is the defining

431

00:17:01,610 --> 00:17:00,360

characteristic of living systems and

432

00:17:03,829 --> 00:17:01,620

this is very different from physical

433

00:17:06,470 --> 00:17:03,839

systems or engineered systems which are

434

00:17:09,470 --> 00:17:06,480

by a fixed or predetermined uh equation

435

00:17:11,390 --> 00:17:09,480

of motion or or behavior so the future

436

00:17:14,150 --> 00:17:11,400

state of an evolvable system is

437

00:17:15,710 --> 00:17:14,160

inherently unpredictable and never maybe

438

00:17:18,470 --> 00:17:15,720

girdle undecidable don't worry about

439

00:17:20,449 --> 00:17:18,480

that and so this this uh this this

440

00:17:23,270 --> 00:17:20,459

feature means that it's very difficult

441

00:17:25,549 --> 00:17:23,280

to control evolving systems and we'll

442

00:17:27,230 --> 00:17:25,559

come to that we'll turn to that at the

443

00:17:30,169 --> 00:17:27,240

end of The Talk

444

00:17:33,049 --> 00:17:30,179

now what do most biologists do well most

445

00:17:34,850 --> 00:17:33,059

biologists uh do something rather

446

00:17:36,890 --> 00:17:34,860

strange you could call it the inverse

447

00:17:40,010 --> 00:17:36,900

problem imagine that you came down from

448

00:17:42,350 --> 00:17:40,020

Mars and I gave you my computer and you

449

00:17:45,110 --> 00:17:42,360

had no idea what this thing was what

450

00:17:47,270 --> 00:17:45,120

would you be able to do to figure out

451

00:17:49,490 --> 00:17:47,280

that this thing is not just a an

452

00:17:50,630 --> 00:17:49,500

expensive door stop but actually as a

453

00:17:52,310 --> 00:17:50,640

universal turing machine with a

454

00:17:54,049 --> 00:17:52,320

vulnerable human architecture it would

455

00:17:56,810 --> 00:17:54,059

be very very different very very

456

00:17:59,029 --> 00:17:56,820

difficult to figure out from the

457

00:18:01,190 --> 00:17:59,039

electronic circuits and the hardware and

458

00:18:04,070 --> 00:18:01,200

so on but that's what the thing actually

459

00:18:06,169 --> 00:18:04,080

did and so what we want to do in biology

460

00:18:08,330 --> 00:18:06,179

is we have the inverse problem the

461

00:18:10,370 --> 00:18:08,340

biology is already created and we want

462

00:18:13,310 --> 00:18:10,380

to understand one is the abstract theory

463

00:18:14,810 --> 00:18:13,320

of which it is an instantiation and that

464

00:18:16,730 --> 00:18:14,820

abstract Theory would underline all

465

00:18:19,310 --> 00:18:16,740

systems that exhibit the characteristics

466

00:18:21,169 --> 00:18:19,320

of life so could you could you if you

467

00:18:22,730 --> 00:18:21,179

didn't know about the universal Turing

468

00:18:25,789 --> 00:18:22,740

machines with a Von Neumann architecture

469

00:18:28,850 --> 00:18:25,799

could you deduce a theoretical framework

470

00:18:31,250 --> 00:18:28,860

just by somebody giving you to a highly

471

00:18:33,289 --> 00:18:31,260

evolved computer

472

00:18:35,210 --> 00:18:33,299

okay we've talked about abstraction so

473

00:18:37,549 --> 00:18:35,220

now let's get down to a real abstraction

474

00:18:40,909 --> 00:18:37,559

so I want to talk about the genetic code

475

00:18:43,490 --> 00:18:40,919

and I figuratively find that people from

476

00:18:45,049 --> 00:18:43,500

various wide-ranging audiences don't

477

00:18:47,270 --> 00:18:45,059

quite know what I mean when I talk about

478

00:18:50,750 --> 00:18:47,280

the genetic code so let's just take a

479

00:18:54,230 --> 00:18:50,760

pause to uh to go through that so in the

480

00:18:56,750 --> 00:18:54,240

modern world as you know DNA contains

481

00:19:00,789 --> 00:18:56,760

our genome and the DNA is built from

482

00:19:04,250 --> 00:19:00,799

four nucleotide bases RNA polymerase

483

00:19:07,549 --> 00:19:04,260

reads the the gene coding segments some

484

00:19:09,770 --> 00:19:07,559

spits out mRNA that's also built from

485

00:19:12,350 --> 00:19:09,780

four nucleotide bases and then the

486

00:19:14,690 --> 00:19:12,360

ribosomes go along with the MRNA and

487

00:19:17,150 --> 00:19:14,700

they spit out the proteins and they

488

00:19:18,610 --> 00:19:17,160

choose which proteins should go into the

489

00:19:21,169 --> 00:19:18,620

protein

490

00:19:23,750 --> 00:19:21,179

the issues which amino acids should go

491

00:19:25,970 --> 00:19:23,760

into the proteins from the code that

492

00:19:28,430 --> 00:19:25,980

they're reading from the from the MRNA

493

00:19:31,029 --> 00:19:28,440

and the way they read that code is they

494

00:19:33,950 --> 00:19:31,039

read it in triplets so

495

00:19:36,890 --> 00:19:33,960

a-u-g-a-c-a GGG and so on these are

496

00:19:39,830 --> 00:19:36,900

codon Triplets of of

497

00:19:42,049 --> 00:19:39,840

of nucleotide bases and the genetic code

498

00:19:46,850 --> 00:19:42,059

it tells you if you read this thing here

499

00:19:48,830 --> 00:19:46,860

what amino acid is going to go into the

500

00:19:51,169 --> 00:19:48,840

into the protein that you're building

501
00:19:53,450 --> 00:19:51,179
and so this is a sort of cartoon here of

502
00:19:54,850 --> 00:19:53,460
the whole translation process and you're

503
00:19:58,789 --> 00:19:54,860
supposed to think of this huge machine

504
00:20:01,010 --> 00:19:58,799
uh moving along like so

505
00:20:03,470 --> 00:20:01,020
so just to summarize what the genetic

506
00:20:05,210 --> 00:20:03,480
code is it's a map it's a map used by

507
00:20:08,450 --> 00:20:05,220
the ribosome to translate the message

508
00:20:11,570 --> 00:20:08,460
from n1a Triplets of four bases into the

509
00:20:14,810 --> 00:20:11,580
20 amino acids of life and uh and and

510
00:20:18,590 --> 00:20:14,820
we're going to discuss uh how that code

511
00:20:21,289 --> 00:20:18,600
evolved now this is Carl woes sitting uh

512
00:20:23,150 --> 00:20:21,299
in his office on and on the New York

513
00:20:27,890 --> 00:20:23,160

Times front page Thursday November the

514

00:20:29,870 --> 00:20:27,900

3rd 1977. why is he there well it says

515

00:20:32,990 --> 00:20:29,880

here scientists discover a form of life

516

00:20:35,090 --> 00:20:33,000

that predates higher organisms and I

517

00:20:37,370 --> 00:20:35,100

guess fake news is not just a new

518

00:20:39,169 --> 00:20:37,380

invention it happened uh it happened

519

00:20:42,049 --> 00:20:39,179

back in the 70s as well this is

520

00:20:44,210 --> 00:20:42,059

partially true not not not not quite

521

00:20:47,930 --> 00:20:44,220

true but in any case he had discovered

522

00:20:50,630 --> 00:20:47,940

uh the uh the archaea so let me just

523

00:20:53,029 --> 00:20:50,640

tell you uh what he had discovered so

524

00:20:56,210 --> 00:20:53,039

this is the tree of life this is from a

525

00:20:58,310 --> 00:20:56,220

paper by Norm Pace in 97

526

00:21:01,610 --> 00:20:58,320

now you can see here there are three

527

00:21:05,090 --> 00:21:01,620

domains the bacteria the archaea and the

528

00:21:08,270 --> 00:21:05,100

eukaryotes you are over here virtually

529

00:21:10,370 --> 00:21:08,280

everything else here is is microbial and

530

00:21:12,650 --> 00:21:10,380

uh the and this this this phylogenetic

531

00:21:14,930 --> 00:21:12,660

tree is a kind of map it's built it's

532

00:21:17,330 --> 00:21:14,940

been elaborated on by now and there's

533

00:21:19,490 --> 00:21:17,340

there's uh it's it's out of date and

534

00:21:21,650 --> 00:21:19,500

there's uh some debates about whether

535

00:21:23,330 --> 00:21:21,660

there's two domains or three domains and

536

00:21:25,970 --> 00:21:23,340

so on and so forth but fundamentally

537

00:21:27,950 --> 00:21:25,980

this is what uh what he discovered now

538

00:21:31,190 --> 00:21:27,960

how did he uh how did he discover this

539

00:21:34,909 --> 00:21:31,200

well what he did was looked for patterns

540

00:21:37,549 --> 00:21:34,919

in uh in in molecular sequences from

541

00:21:39,710 --> 00:21:37,559

parts of the ribosome the 16s small

542

00:21:42,110 --> 00:21:39,720

subunit of the ribosome and by looking

543

00:21:44,510 --> 00:21:42,120

at those sequences was able to look at

544

00:21:46,909 --> 00:21:44,520

do the what what today would call

545

00:21:48,830 --> 00:21:46,919

comparative genomics and map out uh the

546

00:21:51,350 --> 00:21:48,840

the this tree of life

547

00:21:53,510 --> 00:21:51,360

and some around here is uh the last

548

00:21:56,570 --> 00:21:53,520

Universal common ancestor or the last

549

00:21:58,310 --> 00:21:56,580

Universal common ancestral community

550

00:22:02,510 --> 00:21:58,320

so this is the paper that they wrote in

551
00:22:04,549 --> 00:22:02,520
in 1977 and uh the the mystery that this

552
00:22:07,549 --> 00:22:04,559
uh this this work

553
00:22:09,830 --> 00:22:07,559
um uh left us with is the following we

554
00:22:11,510 --> 00:22:09,840
know that the planet is about 4.6

555
00:22:14,690 --> 00:22:11,520
billion years old

556
00:22:17,990 --> 00:22:14,700
we know that the the last Universal

557
00:22:19,850 --> 00:22:18,000
common ancestor even then was uh was

558
00:22:22,430 --> 00:22:19,860
dated to at least three billion years

559
00:22:24,470 --> 00:22:22,440
today we think it's about 3.6 3.8

560
00:22:27,890 --> 00:22:24,480
billion years depending on who you're

561
00:22:28,549 --> 00:22:27,900
talking to based on uh static

562
00:22:37,730 --> 00:22:28,559
um

563
00:22:40,490 --> 00:22:37,740

you know if they're various geological

564

00:22:41,330 --> 00:22:40,500

evidence and and so on for matalites and

565

00:22:43,610 --> 00:22:41,340

so on

566

00:22:46,669 --> 00:22:43,620

um so so basically but something like

567

00:22:49,549 --> 00:22:46,679

this but but the point that that woes

568

00:22:51,710 --> 00:22:49,559

and fox were making is that a lot of the

569

00:22:53,570 --> 00:22:51,720

of the time the planet was inhospitable

570

00:22:57,049 --> 00:22:53,580

to life you had less than a billion

571

00:22:58,730 --> 00:22:57,059

years in which life could evolve and it

572

00:23:01,310 --> 00:22:58,740

evolved the complexity of something like

573

00:23:03,350 --> 00:23:01,320

the modern cell in less than a billion

574

00:23:05,090 --> 00:23:03,360

years and then after that there wasn't

575

00:23:07,370 --> 00:23:05,100

very much cellular Evolution maybe

576

00:23:08,930 --> 00:23:07,380

dinosaurs or multicellularity and things

577

00:23:10,789 --> 00:23:08,940

like that but from a point of view of

578

00:23:12,289 --> 00:23:10,799

the architecture of the cell uh very

579

00:23:16,070 --> 00:23:12,299

little

580

00:23:17,750 --> 00:23:16,080

so so what uh What uh uh woes and fox uh

581

00:23:20,630 --> 00:23:17,760

here's some pictures of them doing their

582

00:23:24,169 --> 00:23:20,640

work at the time uh what they what they

583

00:23:27,049 --> 00:23:24,179

uh what they wrote was that uh that it

584

00:23:29,450 --> 00:23:27,059

wasn't that the evolution speeded up at

585

00:23:31,970 --> 00:23:29,460

the beginning and then slowed down uh

586

00:23:33,830 --> 00:23:31,980

the last Universal common ancestor what

587

00:23:37,070 --> 00:23:33,840

they wrote was that actually maybe

588

00:23:38,750 --> 00:23:37,080

Evolution had a different character

589

00:23:41,090 --> 00:23:38,760

um in its early phases and we're going

590

00:23:43,370 --> 00:23:41,100

to see that there is evidence for that

591

00:23:45,289 --> 00:23:43,380

now what kind of different mode could

592

00:23:48,049 --> 00:23:45,299

there be of evolution

593

00:23:50,390 --> 00:23:48,059

well most of us when you think about

594

00:23:52,970 --> 00:23:50,400

Evolution you think about what is really

595

00:23:55,190 --> 00:23:52,980

called vertical Evolution that is you

596

00:23:56,810 --> 00:23:55,200

have your genes you give your genes to

597

00:23:58,610 --> 00:23:56,820

your children they give their genes to

598

00:24:01,430 --> 00:23:58,620

their children and so on and so forth

599

00:24:04,070 --> 00:24:01,440

and so there's a a transfer of genetic

600

00:24:05,930 --> 00:24:04,080

material of genes through the

601
00:24:08,690 --> 00:24:05,940
generations

602
00:24:11,210 --> 00:24:08,700
horizontal Gene transfer is a different

603
00:24:13,909 --> 00:24:11,220
thing altogether horizontal Gene

604
00:24:16,250 --> 00:24:13,919
transfer is the transfer of genes from

605
00:24:19,250 --> 00:24:16,260
one organism to another that it is not

606
00:24:22,909 --> 00:24:19,260
related to and I and this is uh this is

607
00:24:24,770 --> 00:24:22,919
what happens uh in in bacteria there's

608
00:24:27,409 --> 00:24:24,780
three ways that this can are known to

609
00:24:29,450 --> 00:24:27,419
happen here on Earth genes can be

610
00:24:31,970 --> 00:24:29,460
transmitted through viruses through

611
00:24:34,070 --> 00:24:31,980
direct contact or through uptake of free

612
00:24:37,730 --> 00:24:34,080
DNA from the environment so the question

613
00:24:40,190 --> 00:24:37,740

is what happens when all the all the

614

00:24:42,649 --> 00:24:40,200

microbes in the world do this what

615

00:24:45,590 --> 00:24:42,659

happens when all of early life is able

616

00:24:47,450 --> 00:24:45,600

to uh to transfer genes

617

00:24:50,950 --> 00:24:47,460

okay let me just give you two quick uh

618

00:24:53,690 --> 00:24:50,960

anecdotes about that so this here is a

619

00:24:56,630 --> 00:24:53,700

cyanophage it's a it's a phage that's in

620

00:24:58,270 --> 00:24:56,640

in facts uh prochlorococcus one of the

621

00:25:01,789 --> 00:24:58,280

most abundant organisms of the planet

622

00:25:04,669 --> 00:25:01,799

and uh and and this here is a is a

623

00:25:07,610 --> 00:25:04,679

phylogenetic tree of the of a gene that

624

00:25:10,909 --> 00:25:07,620

is involved in the in photosystem too

625

00:25:12,049 --> 00:25:10,919

and if you can read phylogenetic trees

626

00:25:14,330 --> 00:25:12,059

it doesn't matter if you can't but if

627

00:25:16,850 --> 00:25:14,340

you can read them what this shows you is

628

00:25:19,669 --> 00:25:16,860

that this Gene was transferred back and

629

00:25:23,990 --> 00:25:19,679

forth between a virus and the bacterial

630

00:25:26,450 --> 00:25:24,000

host multiple times during evolution

631

00:25:28,430 --> 00:25:26,460

and in fact the the the group that

632

00:25:31,310 --> 00:25:28,440

discovered this solid metal in

633

00:25:34,070 --> 00:25:31,320

planetism's lab they wrote that to host

634

00:25:35,630 --> 00:25:34,080

like genes acquired by phages undergo a

635

00:25:38,090 --> 00:25:35,640

period of diversification and phase

636

00:25:40,909 --> 00:25:38,100

genomes and serve as a genetic reservoir

637

00:25:43,370 --> 00:25:40,919

for their hosts so the idea is I have a

638

00:25:46,730 --> 00:25:43,380

gene that is a photosynthesis Gene that

639

00:25:49,070 --> 00:25:46,740

that Gene helps in photosynthesis that

640

00:25:50,990 --> 00:25:49,080

Gene gets transferred by a viral attack

641

00:25:54,529 --> 00:25:51,000

to phage

642

00:25:57,529 --> 00:25:54,539

in phage that Gene can evolve much more

643

00:25:59,149 --> 00:25:57,539

rapidly because there are less proof

644

00:26:02,570 --> 00:25:59,159

readings and things like this that go on

645

00:26:06,049 --> 00:26:02,580

in Phase replication so as a result the

646

00:26:08,090 --> 00:26:06,059

bacteria are get infected by new genes

647

00:26:09,710 --> 00:26:08,100

from the phage but those genes have

648

00:26:11,990 --> 00:26:09,720

evolved much more rapidly in the phase

649

00:26:14,090 --> 00:26:12,000

than the wooden bacteria and so there's

650

00:26:17,810 --> 00:26:14,100

a there's a mechanism by which you could

651
00:26:20,210 --> 00:26:17,820
have rapid evolutionary change mediated

652
00:26:21,950 --> 00:26:20,220
by phage or by other mechanisms of

653
00:26:23,870 --> 00:26:21,960
horizontal Gene transfer and because

654
00:26:26,330 --> 00:26:23,880
that is a network effect it's

655
00:26:29,149 --> 00:26:26,340
extraordinarily efficient

656
00:26:30,890 --> 00:26:29,159
and uh and um I'm not going to have time

657
00:26:33,289 --> 00:26:30,900
to show you work that we did actually

658
00:26:36,049 --> 00:26:33,299
modeling that that whole process

659
00:26:38,390 --> 00:26:36,059
now this is the uh the uh with that

660
00:26:40,490 --> 00:26:38,400
having said that and told you about an

661
00:26:42,710 --> 00:26:40,500
other mode of transfer let me now tell

662
00:26:45,110 --> 00:26:42,720
you about the genetic code so here is

663
00:26:48,470 --> 00:26:45,120

the genetic code so the way you read it

664

00:26:50,450 --> 00:26:48,480

is like this you you and then the First

665

00:26:52,669 --> 00:26:50,460

Column up here so that brings you to

666

00:26:54,049 --> 00:26:52,679

this cell that's phenylalanyl in and you

667

00:26:56,990 --> 00:26:54,059

can do the same thing for all of these

668

00:27:00,169 --> 00:26:57,000

of course it's a it's a it's a code of

669

00:27:02,090 --> 00:27:00,179

triplets of for a nucleotide basis an

670

00:27:03,590 --> 00:27:02,100

alphabet of four so in principle there

671

00:27:05,990 --> 00:27:03,600

are 64 things you could code for but

672

00:27:09,230 --> 00:27:06,000

there's only 20 amino acids so the code

673

00:27:11,810 --> 00:27:09,240

is redundant and uh but it's not just

674

00:27:13,310 --> 00:27:11,820

redundant it also has structure so if

675

00:27:15,169 --> 00:27:13,320

you look here these are the most

676
00:27:16,970 --> 00:27:15,179
hydrophobic amino acids these are the

677
00:27:18,289 --> 00:27:16,980
most hydrophilic ones and you can see

678
00:27:20,930 --> 00:27:18,299
that in the way that this code is

679
00:27:25,549 --> 00:27:20,940
written there is structure here

680
00:27:28,070 --> 00:27:25,559
the amino acids have are segmented in

681
00:27:28,850 --> 00:27:28,080
this in this uh in this genetic code

682
00:27:31,130 --> 00:27:28,860
table

683
00:27:34,730 --> 00:27:31,140
so one of the things that Carl was did

684
00:27:36,049 --> 00:27:34,740
back in the 1960s was to measure a

685
00:27:38,330 --> 00:27:36,059
quantity that he called polar

686
00:27:39,830 --> 00:27:38,340
acquirement which measured this balance

687
00:27:42,409 --> 00:27:39,840
between hydrophobicity and

688
00:27:45,289 --> 00:27:42,419

hydrophilicity and gave a single number

689

00:27:48,169 --> 00:27:45,299

which is small upper over here and large

690

00:27:51,710 --> 00:27:48,179

over here and and so he was able to

691

00:27:54,529 --> 00:27:51,720

quantify that chemical difference

692

00:27:56,870 --> 00:27:54,539

now you all know that the genetic code

693

00:27:58,130 --> 00:27:56,880

is pretty much Universal it's not

694

00:27:59,870 --> 00:27:58,140

exactly Universal there's small

695

00:28:01,850 --> 00:27:59,880

variations and stop codons but it's

696

00:28:02,930 --> 00:28:01,860

basically Universal but what I want to

697

00:28:04,549 --> 00:28:02,940

tell you now is something that you may

698

00:28:07,730 --> 00:28:04,559

not know about and that is that the

699

00:28:09,830 --> 00:28:07,740

genetic code is pretty much optimal in

700

00:28:12,049 --> 00:28:09,840

minimizing errors

701

00:28:14,510 --> 00:28:12,059

okay so let's let's uh let's discuss

702

00:28:16,190 --> 00:28:14,520

what we mean by that so let's suppose

703

00:28:18,769 --> 00:28:16,200

that you were given the task of of

704

00:28:21,769 --> 00:28:18,779

Designing intelligently a genetic code

705

00:28:23,930 --> 00:28:21,779

okay well you might say well translation

706

00:28:25,789 --> 00:28:23,940

is fundamentally important to a cellular

707

00:28:28,310 --> 00:28:25,799

operation so we want to make sure that

708

00:28:31,909 --> 00:28:28,320

any any mistakes any mutations or any

709

00:28:33,529 --> 00:28:31,919

misreadings give you an amino acid which

710

00:28:35,690 --> 00:28:33,539

is pretty close in chemical properties

711

00:28:37,190 --> 00:28:35,700

to the one that you should have got and

712

00:28:40,010 --> 00:28:37,200

if you could design a code like that

713

00:28:42,950 --> 00:28:40,020

then then that would be great okay it

714

00:28:46,310 --> 00:28:42,960

would be robust to errors so the

715

00:28:49,010 --> 00:28:46,320

question is is our genetic code like

716

00:28:51,529 --> 00:28:49,020

that I'm going to show you that it is

717

00:28:53,090 --> 00:28:51,539

so here's the actual genetic code so

718

00:28:55,669 --> 00:28:53,100

what you can do is you can make in the

719

00:28:58,130 --> 00:28:55,679

computer alternative genetic codes just

720

00:28:59,990 --> 00:28:58,140

by permuting the labels so here I'm

721

00:29:02,149 --> 00:29:00,000

permuting the label so I get new codes

722

00:29:04,310 --> 00:29:02,159

I'll be it with the same pattern of

723

00:29:06,890 --> 00:29:04,320

degeneracy there's 20 factorial which is

724

00:29:08,930 --> 00:29:06,900

about 10 to the 18 possible genetic code

725

00:29:11,090 --> 00:29:08,940

that you could have in the computer

726

00:29:14,930 --> 00:29:11,100

okay so now I can say all right I've

727

00:29:17,269 --> 00:29:14,940

made this whole Suite of genetic codes

728

00:29:20,389 --> 00:29:17,279

how good are they at minimizing errors

729

00:29:22,970 --> 00:29:20,399

and uh and there's a way that you can

730

00:29:25,430 --> 00:29:22,980

you can compute that and I'm not going

731

00:29:27,049 --> 00:29:25,440

to go into the exact metric that one

732

00:29:29,210 --> 00:29:27,059

uses

733

00:29:31,669 --> 00:29:29,220

so there's a way that one can do that so

734

00:29:34,430 --> 00:29:31,679

then one can ask well what should be the

735

00:29:35,889 --> 00:29:34,440

output if we take all our genetic codes

736

00:29:38,210 --> 00:29:35,899

that we've constructed in the computer

737

00:29:40,070 --> 00:29:38,220

measure how good they are at minimizing

738

00:29:42,830 --> 00:29:40,080

errors and then plot the probability

739

00:29:44,810 --> 00:29:42,840

distribution how many times we see a

740

00:29:47,450 --> 00:29:44,820

particular code with a particular score

741

00:29:49,610 --> 00:29:47,460

and minimizing errors and the smaller

742

00:29:51,649 --> 00:29:49,620

the the number here is on the horizontal

743

00:29:53,149 --> 00:29:51,659

axis the better the code is at

744

00:29:55,370 --> 00:29:53,159

minimizing error

745

00:29:57,230 --> 00:29:55,380

okay so one possibility that you could

746

00:29:59,810 --> 00:29:57,240

have is something like this you've got

747

00:30:02,269 --> 00:29:59,820

some you know Bells roughly bell-shaped

748

00:30:03,950 --> 00:30:02,279

curve and uh and then you that's what

749

00:30:05,570 --> 00:30:03,960

you would get for any random genetic

750

00:30:07,250 --> 00:30:05,580

code and then you look at the actual

751

00:30:09,289 --> 00:30:07,260

genetic code it happens to be here in

752

00:30:11,330 --> 00:30:09,299

the middle in this uh in this sketch and

753

00:30:14,210 --> 00:30:11,340

so you would say okay well if that's

754

00:30:16,549 --> 00:30:14,220

what happens then that means that the

755

00:30:19,730 --> 00:30:16,559

current genetic code is just a frozen

756

00:30:21,289 --> 00:30:19,740

accident there were some ancestral

757

00:30:23,750 --> 00:30:21,299

organism

758

00:30:25,190 --> 00:30:23,760

it by accident it happens to be the one

759

00:30:28,430 --> 00:30:25,200

that we're all descended from all life

760

00:30:30,470 --> 00:30:28,440

on Earth it had some genetic code we all

761

00:30:32,389 --> 00:30:30,480

have the same genetic code as it because

762

00:30:36,289 --> 00:30:32,399

if we had a different genetic code then

763

00:30:37,789 --> 00:30:36,299

we'd be mistranslating our genomes we'd

764

00:30:39,350 --> 00:30:37,799

be getting the long amino acids and the

765

00:30:42,529 --> 00:30:39,360

wrong proteins and so we wouldn't

766

00:30:45,409 --> 00:30:42,539

survive and so the code must be what

767

00:30:47,750 --> 00:30:45,419

Francis Crick in 1968 called a frozen

768

00:30:49,549 --> 00:30:47,760

accident it's an accident because it

769

00:30:51,710 --> 00:30:49,559

just comes from whatever was the last

770

00:30:54,289 --> 00:30:51,720

Universal common ancestor and it's

771

00:30:57,710 --> 00:30:54,299

frozen because if it evolves the changes

772

00:31:00,830 --> 00:30:57,720

that it would happen would be deadly

773

00:31:02,990 --> 00:31:00,840

well the other option is something like

774

00:31:05,029 --> 00:31:03,000

this you've got a bell-shaped curve like

775

00:31:06,830 --> 00:31:05,039

this and then the attribution of the

776
00:31:09,529 --> 00:31:06,840
code is somewhere down here in the Tails

777
00:31:11,690 --> 00:31:09,539
and if that's true then that says heck

778
00:31:13,970 --> 00:31:11,700
the genetic code that we have is not a

779
00:31:17,210 --> 00:31:13,980
frozen accident it had to have have

780
00:31:19,010 --> 00:31:17,220
evolved so here are the data this was a

781
00:31:22,669 --> 00:31:19,020
these data taken from an experiment that

782
00:31:25,190 --> 00:31:22,679
was done by freelance Hearst in 1998 so

783
00:31:27,110 --> 00:31:25,200
they they generated 1 million genetic

784
00:31:29,029 --> 00:31:27,120
codes and they scored them in a way

785
00:31:31,010 --> 00:31:29,039
they're like I'm not going to go into in

786
00:31:33,950 --> 00:31:31,020
detail and the actual genetic code is

787
00:31:35,810 --> 00:31:33,960
way way down here in the tail so all

788
00:31:38,149 --> 00:31:35,820

these random codes look nothing like

789

00:31:41,149 --> 00:31:38,159

this actual universal genetic code the

790

00:31:43,070 --> 00:31:41,159

canonical genetic code and so the title

791

00:31:44,750 --> 00:31:43,080

of their paper was the genetic code is

792

00:31:47,090 --> 00:31:44,760

one in a million

793

00:31:49,909 --> 00:31:47,100

can you generate a million genetic codes

794

00:31:52,310 --> 00:31:49,919

and and they're all worse than the one

795

00:31:54,049 --> 00:31:52,320

that we actually have at minimizing

796

00:31:55,549 --> 00:31:54,059

translation hours

797

00:31:57,230 --> 00:31:55,559

actually we know that actually it's

798

00:32:00,169 --> 00:31:57,240

actually more more like a hundred times

799

00:32:02,389 --> 00:32:00,179

uh better than that

800

00:32:04,970 --> 00:32:02,399

okay so now we have to ask the question

801
00:32:06,649 --> 00:32:04,980
how did the genetic code get like this

802
00:32:09,049 --> 00:32:06,659
how is it possible for the code to

803
00:32:11,330 --> 00:32:09,059
evolve because Florence is quick already

804
00:32:13,310 --> 00:32:11,340
told us that it can't evolve if you so

805
00:32:14,870 --> 00:32:13,320
if you change the genetic code you're

806
00:32:16,490 --> 00:32:14,880
going to start making the wrong amino

807
00:32:18,769 --> 00:32:16,500
acids you make your own amino acids you

808
00:32:20,750 --> 00:32:18,779
make the wrong proteins everything dies

809
00:32:24,409 --> 00:32:20,760
so we have to figure out how to do it

810
00:32:26,810 --> 00:32:24,419
and and this is what we did uh in in

811
00:32:28,490 --> 00:32:26,820
this paper over here and I want to walk

812
00:32:31,190 --> 00:32:28,500
you through not I'm not going to go into

813
00:32:33,350 --> 00:32:31,200

any of the the modeling and the math and

814

00:32:35,870 --> 00:32:33,360

so on I want to give you a feel of how

815

00:32:38,990 --> 00:32:35,880

we can understand how it is possible for

816

00:32:40,310 --> 00:32:39,000

a code to evolve

817

00:32:41,930 --> 00:32:40,320

okay so we're going to do a thought

818

00:32:44,990 --> 00:32:41,940

experiment and we're going to do the

819

00:32:48,169 --> 00:32:45,000

thought experiment by involving in our

820

00:32:54,049 --> 00:32:48,179

little story here the experts on codes

821

00:33:00,830 --> 00:32:57,529

spies you're right

822

00:33:04,490 --> 00:33:00,840

these characters from from from bad and

823

00:33:05,870 --> 00:33:04,500

possibly sexist 1960s TV shows

824

00:33:08,389 --> 00:33:05,880

all right so we're going to do an

825

00:33:10,549 --> 00:33:08,399

experiment that involves uh these spies

826

00:33:12,409 --> 00:33:10,559

and we're going to imagine that the

827

00:33:13,430 --> 00:33:12,419

spies of course have their secret code

828

00:33:18,409 --> 00:33:13,440

book

829

00:33:20,149 --> 00:33:18,419

are trying to communicate with uh one

830

00:33:22,070 --> 00:33:20,159

disreputable member of their Community

831

00:33:23,269 --> 00:33:22,080

shown here on the right and so we're

832

00:33:25,789 --> 00:33:23,279

going to do a thought experiment about

833

00:33:27,529 --> 00:33:25,799

what can happen when one spy tries to

834

00:33:30,049 --> 00:33:27,539

talk to to the other

835

00:33:32,630 --> 00:33:30,059

so let's start off with a with a message

836

00:33:35,149 --> 00:33:32,640

which is emitted over here so this is

837

00:33:38,570 --> 00:33:35,159

the message that she wants to send

838

00:33:41,029 --> 00:33:38,580

that is a received by by uh the the

839

00:33:44,029 --> 00:33:41,039

person on the right uses their code

840

00:33:47,570 --> 00:33:44,039

block and they correctly decode it as as

841

00:33:50,210 --> 00:33:47,580

uh as that sequence of uh of amino acids

842

00:33:52,070 --> 00:33:50,220

so so far everything is good there's

843

00:33:55,190 --> 00:33:52,080

only a single message that you can

844

00:33:57,409 --> 00:33:55,200

deduce from this signal that you receive

845

00:33:58,490 --> 00:33:57,419

okay so this is the standard operating

846

00:34:01,130 --> 00:33:58,500

procedure

847

00:34:03,590 --> 00:34:01,140

but the person on the right was chosen

848

00:34:06,769 --> 00:34:03,600

not just for their for their glamorous

849

00:34:08,450 --> 00:34:06,779

sartorial style but for the fact that

850

00:34:10,849 --> 00:34:08,460

they're very uh

851
00:34:13,190 --> 00:34:10,859
um incompetent and so I want you to

852
00:34:14,990 --> 00:34:13,200
imagine that this person has lost half

853
00:34:19,070 --> 00:34:15,000
the code book

854
00:34:20,869 --> 00:34:19,080
and so the code has now been uh changed

855
00:34:23,450 --> 00:34:20,879
because you've missed half the code book

856
00:34:25,369 --> 00:34:23,460
and so now he translates it as equals m

857
00:34:27,589 --> 00:34:25,379
c squared which means nothing to him but

858
00:34:28,909 --> 00:34:27,599
it may mean something to to you and so

859
00:34:31,369 --> 00:34:28,919
what we've learned from this is that if

860
00:34:33,230 --> 00:34:31,379
you evolve or change the code

861
00:34:36,129 --> 00:34:33,240
in this case by losing half the code

862
00:34:39,050 --> 00:34:36,139
book the message gets garbled so so far

863
00:34:40,909 --> 00:34:39,060

Crick was right

864

00:34:43,790 --> 00:34:40,919

suppose however

865

00:34:45,409 --> 00:34:43,800

that we have a statistical code book not

866

00:34:47,690 --> 00:34:45,419

a code book that gives you one message

867

00:34:49,010 --> 00:34:47,700

but a code book that gives you an

868

00:34:51,169 --> 00:34:49,020

ensemble of messages

869

00:34:52,970 --> 00:34:51,179

and from those messages you look at them

870

00:34:54,430 --> 00:34:52,980

and you say oh that makes no sense that

871

00:34:57,530 --> 00:34:54,440

makes no sense that makes it says oh

872

00:34:59,570 --> 00:34:57,540

phenylalum okay great perfect this must

873

00:35:03,109 --> 00:34:59,580

be what they what they meant if you have

874

00:35:04,730 --> 00:35:03,119

a code plus it's context then if you if

875

00:35:07,070 --> 00:35:04,740

you just have a probabilistic code book

876

00:35:08,690 --> 00:35:07,080

you have a chance of being able to

877

00:35:10,849 --> 00:35:08,700

interpret the message

878

00:35:12,829 --> 00:35:10,859

so the idea then was that if you have a

879

00:35:15,130 --> 00:35:12,839

polar ballistic code book then that

880

00:35:17,870 --> 00:35:15,140

means that you may you may need to have

881

00:35:19,790 --> 00:35:17,880

statistical proteins a process of

882

00:35:22,910 --> 00:35:19,800

translation that doesn't Just Produce

883

00:35:24,829 --> 00:35:22,920

one protein but produces many

884

00:35:27,710 --> 00:35:24,839

and this would make complete sense

885

00:35:30,050 --> 00:35:27,720

because think about early life think

886

00:35:32,870 --> 00:35:30,060

about early life which we know was a was

887

00:35:35,030 --> 00:35:32,880

a dominated by endosymbiosis and all

888

00:35:37,190 --> 00:35:35,040

sorts of events like that which of

889

00:35:40,130 --> 00:35:37,200

course led to many of the structures

890

00:35:42,650 --> 00:35:40,140

that we see in in modern cells uh like

891

00:35:45,589 --> 00:35:42,660

mitochondria and chloroplasts and so on

892

00:35:48,770 --> 00:35:45,599

so we can imagine that early life was a

893

00:35:51,230 --> 00:35:48,780

bit like early automobiles okay remember

894

00:35:52,930 --> 00:35:51,240

how early automobiles were they a

895

00:35:54,829 --> 00:35:52,940

hundred years ago a bit more than that

896

00:35:57,470 --> 00:35:54,839

automobiles did not look like they do

897

00:35:58,970 --> 00:35:57,480

today they were rickety old things they

898

00:36:01,250 --> 00:35:58,980

were sort of held together by string

899

00:36:04,010 --> 00:36:01,260

ceiling wax and if I drove over to one

900

00:36:05,930 --> 00:36:04,020

of my friends in my car and uh and then

901

00:36:07,849 --> 00:36:05,940

the wheel fell off

902

00:36:09,589 --> 00:36:07,859

you know she would just say well no

903

00:36:11,270 --> 00:36:09,599

problem I've got an old bicycle in the

904

00:36:13,370 --> 00:36:11,280

garage here we'll just screw on the

905

00:36:16,430 --> 00:36:13,380

wheel of that old bicycle onto your car

906

00:36:18,230 --> 00:36:16,440

and you'll go you're good to go

907

00:36:20,030 --> 00:36:18,240

that you could do you could mix and

908

00:36:22,730 --> 00:36:20,040

match parts

909

00:36:23,750 --> 00:36:22,740

100 years ago 120 years ago in the early

910

00:36:26,690 --> 00:36:23,760

class

911

00:36:29,450 --> 00:36:26,700

try to try doing that today to a to a

912

00:36:31,010 --> 00:36:29,460

Toyota Corolla right to taking a bicycle

913

00:36:32,990 --> 00:36:31,020

wheel and sticking it on when you've got

914

00:36:35,630 --> 00:36:33,000

a flat tire that's not going to work at

915

00:36:38,030 --> 00:36:35,640

all modern cars are more highly evolved

916

00:36:40,370 --> 00:36:38,040

and so they're very intolerant of

917

00:36:42,770 --> 00:36:40,380

anything that is not exactly right

918

00:36:46,130 --> 00:36:42,780

and so we get the idea that evolved

919

00:36:49,490 --> 00:36:46,140

systems become very intolerant of any

920

00:36:51,349 --> 00:36:49,500

kind of ambiguity in what's present but

921

00:36:54,109 --> 00:36:51,359

systems that are very early on are very

922

00:36:57,410 --> 00:36:54,119

simple are able to tolerate ambiguity

923

00:36:59,870 --> 00:36:57,420

and uh and and and so uh you can have

924

00:37:01,730 --> 00:36:59,880

this idea that the codes are floppy that

925

00:37:03,710 --> 00:37:01,740

the statistical proteins that have been

926

00:37:07,130 --> 00:37:03,720

made are not always the same proteins

927

00:37:09,650 --> 00:37:07,140

and then somehow the messages uh can can

928

00:37:12,410 --> 00:37:09,660

be interpreted so in other words what

929

00:37:15,890 --> 00:37:12,420

I'm saying is that the code book and the

930

00:37:18,530 --> 00:37:15,900

message can co-evolve as the organisms

931

00:37:21,109 --> 00:37:18,540

become more and more complex you get a

932

00:37:23,450 --> 00:37:21,119

probability distribution of codes that

933

00:37:24,770 --> 00:37:23,460

can be the outcome of translation and as

934

00:37:27,530 --> 00:37:24,780

the organisms become more and more

935

00:37:30,410 --> 00:37:27,540

complex that distribution gets narrower

936

00:37:32,270 --> 00:37:30,420

and narrower and very intolerant of any

937

00:37:34,849 --> 00:37:32,280

kind of element

938

00:37:36,410 --> 00:37:34,859

now you might ask yourself well wait

939

00:37:38,050 --> 00:37:36,420

this doesn't make any sense

940

00:37:41,930 --> 00:37:38,060

selection pressure

941

00:37:43,069 --> 00:37:41,940

acts on the phenotype it doesn't act on

942

00:37:44,630 --> 00:37:43,079

the code

943

00:37:47,210 --> 00:37:44,640

but I want to show you that it acts on

944

00:37:49,250 --> 00:37:47,220

the code too okay so here is a thought

945

00:37:51,530 --> 00:37:49,260

experiment but for me it was an actual

946

00:37:53,030 --> 00:37:51,540

experiment so I'm a physicist so I like

947

00:37:55,730 --> 00:37:53,040

to write papers with mathematical

948

00:37:59,089 --> 00:37:55,740

equations and so when I write a paper or

949

00:38:01,849 --> 00:37:59,099

a grant proposal I write it in a Thing

950

00:38:04,250 --> 00:38:01,859

Called Tech a type setting program that

951

00:38:07,190 --> 00:38:04,260

enables you to write equations my

952

00:38:14,510 --> 00:38:07,200

biological colleagues of course use a

953

00:38:20,990 --> 00:38:17,030

I guess the age of satire is not over

954

00:38:22,910 --> 00:38:21,000

yet and so uh so you can imagine the

955

00:38:24,470 --> 00:38:22,920

situation where I have sitting with my

956

00:38:26,089 --> 00:38:24,480

friends and the institute for genomic

957

00:38:28,609 --> 00:38:26,099

biology and I'm saying hey let's write

958

00:38:30,069 --> 00:38:28,619

this proposal together and they say sure

959

00:38:33,650 --> 00:38:30,079

about so we're going to write it in in

960

00:38:35,510 --> 00:38:33,660

word and hasten the my stuff in Tech and

961

00:38:38,030 --> 00:38:35,520

of course you know it's it's a complete

962

00:38:40,550 --> 00:38:38,040

disaster and uh and uh and what happens

963

00:38:42,710 --> 00:38:40,560

is the uh our proposal never actually

964

00:38:45,890 --> 00:38:42,720

gets written it never gets submitted and

965

00:38:47,870 --> 00:38:45,900

so it never gets funded meanwhile down

966

00:38:50,569 --> 00:38:47,880

the corridor another person is

967

00:38:53,450 --> 00:38:50,579

collaborating with their co-workers they

968

00:38:54,770 --> 00:38:53,460

just write it in word no problems and

969

00:38:57,770 --> 00:38:54,780

even if their proposal was less good

970

00:38:59,630 --> 00:38:57,780

than ours it's still uh it still has a

971

00:39:02,569 --> 00:38:59,640

chance of being funded so the code

972

00:39:04,970 --> 00:39:02,579

actually uh does matter

973

00:39:07,069 --> 00:39:04,980

now what is the basic way that the

974

00:39:08,089 --> 00:39:07,079

genetic code evolves in terms of its

975

00:39:10,910 --> 00:39:08,099

context

976

00:39:13,550 --> 00:39:10,920

so here's our here's a um an interesting

977

00:39:16,849 --> 00:39:13,560

uh factoid and this this slide is now

978

00:39:18,349 --> 00:39:16,859

quite old but uh this is uh this you may

979

00:39:20,870 --> 00:39:18,359

not recognize this person this is Bill

980

00:39:23,569 --> 00:39:20,880

Gates uh this is the late uh Steve Jobs

981

00:39:25,609 --> 00:39:23,579

both of them with examples of their of

982

00:39:28,370 --> 00:39:25,619

their of their companies or computers

983

00:39:30,650 --> 00:39:28,380

and uh actually uh my computer is a

984

00:39:33,530 --> 00:39:30,660

Windows computer but many people like

985

00:39:35,030 --> 00:39:33,540

her like the Apple computers and and the

986

00:39:37,849 --> 00:39:35,040

reason that um

987

00:39:39,290 --> 00:39:37,859

you know the the reason I use a Windows

988

00:39:41,770 --> 00:39:39,300

computer well I mean everybody does

989

00:39:44,270 --> 00:39:41,780

right like 96 of all the world's

990

00:39:47,630 --> 00:39:44,280

computers run their windows in a very

991

00:39:49,490 --> 00:39:47,640

small fashion run uh the the Mac

992

00:39:51,530 --> 00:39:49,500

operating system and the reason is that

993

00:39:53,270 --> 00:39:51,540

the Windows operating system is much

994

00:39:57,710 --> 00:39:53,280

better than

995

00:40:03,349 --> 00:40:00,530

well that's a very inopportune time to

996

00:40:05,870 --> 00:40:03,359

have a blue screen of death

997

00:40:09,589 --> 00:40:05,880

there's operating system is to put it

998

00:40:12,710 --> 00:40:09,599

mildly uh rubbish uh it has all sorts of

999

00:40:14,030 --> 00:40:12,720

things like this but the reason why it

1000

00:40:15,950 --> 00:40:14,040

is so popular

1001

00:40:20,150 --> 00:40:15,960

is not because it is the best computer

1002

00:40:23,450 --> 00:40:20,160

system it's because any program that you

1003

00:40:25,430 --> 00:40:23,460

want to run you can find it on Windows

1004

00:40:28,069 --> 00:40:25,440

but you may not be able to find it on

1005

00:40:30,470 --> 00:40:28,079

the Macos that may not be so true today

1006

00:40:32,510 --> 00:40:30,480

but it was certainly true uh suddenly 10

1007

00:40:34,790 --> 00:40:32,520

10 years ago and so what you learn from

1008

00:40:37,550 --> 00:40:34,800

this is that the community with access

1009

00:40:39,410 --> 00:40:37,560

to the broadest range of Innovations has

1010

00:40:41,930 --> 00:40:39,420

an evolutionary Advantage anything that

1011

00:40:43,910 --> 00:40:41,940

you want to do you can find a gadget in

1012

00:40:46,430 --> 00:40:43,920

that operating system that does it and

1013

00:40:48,890 --> 00:40:46,440

so what's important for platforms for

1014

00:40:51,290 --> 00:40:48,900

operating systems for processes that are

1015

00:40:54,650 --> 00:40:51,300

fundamental to cells like the like

1016

00:40:56,450 --> 00:40:54,660

translation is that is that you have the

1017

00:40:59,030 --> 00:40:56,460

broadest reach

1018

00:41:00,589 --> 00:40:59,040

so what we did in our in our

1019

00:41:02,870 --> 00:41:00,599

mathematical model which I'm not going

1020

00:41:05,329 --> 00:41:02,880

to go into in detail was we we are

1021

00:41:07,550 --> 00:41:05,339

considered a simulation a digital life

1022

00:41:09,170 --> 00:41:07,560

simulation just like the computer virus

1023

00:41:10,730 --> 00:41:09,180

once that I showed you at the beginning

1024

00:41:13,430 --> 00:41:10,740

of the call at the beginning of the uh

1025

00:41:15,109 --> 00:41:13,440

of the of the talk the ones uh run by

1026
00:41:17,390 --> 00:41:15,119
Niels Barry Charlie at The Institute for

1027
00:41:19,190 --> 00:41:17,400
advanced study so we have an asexual

1028
00:41:21,589 --> 00:41:19,200
population of evolving reproducing

1029
00:41:24,349 --> 00:41:21,599
digital organisms like computer viruses

1030
00:41:27,950 --> 00:41:24,359
the phenotype is a function of their

1031
00:41:29,990 --> 00:41:27,960
proteins and the proteins are obtained

1032
00:41:32,150 --> 00:41:30,000
by translating the genome with a code

1033
00:41:33,650 --> 00:41:32,160
but with uh with errors the individual

1034
00:41:35,630 --> 00:41:33,660
reproduction rate is a function of

1035
00:41:38,810 --> 00:41:35,640
fitness and the messages change are

1036
00:41:42,230 --> 00:41:38,820
faster than codes and so so forth and so

1037
00:41:45,170 --> 00:41:42,240
everything that's in this system allows

1038
00:41:47,329 --> 00:41:45,180

codes to evolve due to selection of the

1039

00:41:48,770 --> 00:41:47,339

phenotype through the mechanism that I

1040

00:41:50,390 --> 00:41:48,780

was showing you so now what we're doing

1041

00:41:52,010 --> 00:41:50,400

is simulating a whole population of

1042

00:41:54,890 --> 00:41:52,020

different organisms which have different

1043

00:41:57,230 --> 00:41:54,900

codes another question is which code is

1044

00:41:58,970 --> 00:41:57,240

the one that wins

1045

00:42:00,829 --> 00:41:58,980

all right so let's imagine that we've

1046

00:42:02,630 --> 00:42:00,839

done this experiment

1047

00:42:03,710 --> 00:42:02,640

so I started with a bunch of organisms

1048

00:42:05,630 --> 00:42:03,720

all of which have slightly different

1049

00:42:07,310 --> 00:42:05,640

genetic codes and they all co-evolve and

1050

00:42:09,470 --> 00:42:07,320

they're trying to deal with the

1051
00:42:12,589 --> 00:42:09,480
environment that they are they're in and

1052
00:42:14,390 --> 00:42:12,599
we watch how they evolve in time now we

1053
00:42:16,370 --> 00:42:14,400
did two experiments here

1054
00:42:17,569 --> 00:42:16,380
well I'm going to show you this graph

1055
00:42:20,030 --> 00:42:17,579
and I'm going to show another one

1056
00:42:22,190 --> 00:42:20,040
similar to it in the next slide this on

1057
00:42:24,770 --> 00:42:22,200
the vertical axis is the quality of the

1058
00:42:27,890 --> 00:42:24,780
code it's how good the genetic code is

1059
00:42:30,710 --> 00:42:27,900
of those organisms minimizing ever and

1060
00:42:32,630 --> 00:42:30,720
this is time over here and here's what

1061
00:42:34,550 --> 00:42:32,640
happens when you do this with regular

1062
00:42:36,410 --> 00:42:34,560
vertical darwinian Evolution that you're

1063
00:42:39,290 --> 00:42:36,420

used to and you can see that what

1064

00:42:40,970 --> 00:42:39,300

happens is that is as I as I evolve the

1065

00:42:44,089 --> 00:42:40,980

system

1066

00:42:46,670 --> 00:42:44,099

the uh the um the codes get better

1067

00:42:48,589 --> 00:42:46,680

smaller is better and then eventually it

1068

00:42:50,750 --> 00:42:48,599

stops and it just stays constant in time

1069

00:42:52,430 --> 00:42:50,760

and maybe if we waited like 100 times

1070

00:42:53,990 --> 00:42:52,440

longer maybe there'd be some other

1071

00:42:55,670 --> 00:42:54,000

change down here or something like this

1072

00:42:57,530 --> 00:42:55,680

and you run it again and for this one

1073

00:43:00,470 --> 00:42:57,540

you get something like this and you run

1074

00:43:02,630 --> 00:43:00,480

it again you get something like this

1075

00:43:05,690 --> 00:43:02,640

and if you ask

1076

00:43:07,130 --> 00:43:05,700

I've got a whole distribution

1077

00:43:08,750 --> 00:43:07,140

codes here

1078

00:43:10,550 --> 00:43:08,760

um what would I have got at random when

1079

00:43:12,109 --> 00:43:10,560

you can work that out and it would be

1080

00:43:14,569 --> 00:43:12,119

something like this and so what I've

1081

00:43:17,030 --> 00:43:14,579

learned is that without uh in this

1082

00:43:20,750 --> 00:43:17,040

experiment with vertical Evolution only

1083

00:43:23,030 --> 00:43:20,760

I evolve organisms that have codes that

1084

00:43:25,069 --> 00:43:23,040

are indistinguishable from random codes

1085

00:43:26,450 --> 00:43:25,079

and they're not unique and they're

1086

00:43:28,550 --> 00:43:26,460

certainly not optimal

1087

00:43:30,950 --> 00:43:28,560

but if I switch on horizontal Gene

1088

00:43:33,950 --> 00:43:30,960

transfer then what happens is the codes

1089

00:43:36,829 --> 00:43:33,960

follow this blue trajectory here and as

1090

00:43:40,190 --> 00:43:36,839

you can see end up uh with uh with a

1091

00:43:42,530 --> 00:43:40,200

very optimal code and one which is very

1092

00:43:44,809 --> 00:43:42,540

far from what you would get at random

1093

00:43:46,730 --> 00:43:44,819

and so once you've learned from this is

1094

00:43:49,089 --> 00:43:46,740

that the process of horizontal Gene to

1095

00:43:52,250 --> 00:43:49,099

transfer as an evolutionary process

1096

00:43:53,930 --> 00:43:52,260

leads to optimality of the uh of the

1097

00:43:57,109 --> 00:43:53,940

genetic code

1098

00:43:59,690 --> 00:43:57,119

now if we look at uh at uh how many

1099

00:44:02,150 --> 00:43:59,700

codes we have in our system now that's

1100

00:44:04,849 --> 00:44:02,160

shown shown here and again the same

1101

00:44:07,730 --> 00:44:04,859

thing is true that if you just use a

1102

00:44:10,910 --> 00:44:07,740

vertical Evolution uh you have you don't

1103

00:44:12,470 --> 00:44:10,920

get much uh selection of the genetic

1104

00:44:14,690 --> 00:44:12,480

codes as we saw on the previous slide

1105

00:44:17,270 --> 00:44:14,700

and but if you switch on horizontal Gene

1106

00:44:18,050 --> 00:44:17,280

transfer you get a universal genetic

1107

00:44:20,329 --> 00:44:18,060

code

1108

00:44:23,150 --> 00:44:20,339

and so what we've learned from this is

1109

00:44:25,730 --> 00:44:23,160

that the the the phase diagram of Life

1110

00:44:27,770 --> 00:44:25,740

must have looked something like this so

1111

00:44:30,609 --> 00:44:27,780

we're somewhere up here where in that

1112

00:44:34,790 --> 00:44:30,619

blob over here early on

1113

00:44:37,670 --> 00:44:34,800

the evolution was a network process

1114

00:44:40,010 --> 00:44:37,680

shown schematically over here

1115

00:44:41,690 --> 00:44:40,020

rapid Evolution and then over here we

1116

00:44:44,510 --> 00:44:41,700

have the vertical Evolution which we saw

1117

00:44:46,730 --> 00:44:44,520

was incredibly slow and that's the

1118

00:44:49,069 --> 00:44:46,740

process that we are in today and the

1119

00:44:50,870 --> 00:44:49,079

summary over here was a transition that

1120

00:44:53,150 --> 00:44:50,880

uh that Carl was like to call the

1121

00:44:55,849 --> 00:44:53,160

darwinian transition a claimed of a

1122

00:44:58,069 --> 00:44:55,859

phase transition uh between a collective

1123

00:45:01,670 --> 00:44:58,079

Network phase of life and a transition

1124

00:45:05,270 --> 00:45:01,680

to a life where organismal identity and

1125

00:45:10,370 --> 00:45:05,280

individuality becomes more important

1126

00:45:12,950 --> 00:45:10,380

all right so so I I I'm going to uh

1127

00:45:15,470 --> 00:45:12,960

skip my section on Homer care housing so

1128

00:45:17,990 --> 00:45:15,480

I'm just going to skip through that and

1129

00:45:19,309 --> 00:45:18,000

uh and I wanted to tell you about some

1130

00:45:21,770 --> 00:45:19,319

of the things there's a universal in

1131

00:45:23,930 --> 00:45:21,780

biology so anyway the bottom line of

1132

00:45:26,530 --> 00:45:23,940

this is that uh we made a mathematical

1133

00:45:28,210 --> 00:45:26,540

model of the evolution of of of of of

1134

00:45:31,130 --> 00:45:28,220

Kyle

1135

00:45:33,470 --> 00:45:31,140

autocatalytic self-replicators and we

1136

00:45:37,490 --> 00:45:33,480

could show that uh you ultimately end up

1137

00:45:39,890 --> 00:45:37,500

with with broken 100 are broken uh

1138

00:45:42,290 --> 00:45:39,900

chirality not just you get sun

1139

00:45:44,150 --> 00:45:42,300

right-handed or sun left-handed but 100

1140

00:45:46,250 --> 00:45:44,160

effect and that's the thing that we

1141

00:45:49,130 --> 00:45:46,260

observe in biology and that's the thing

1142

00:45:51,650 --> 00:45:49,140

that was difficult to explain and and we

1143

00:45:54,470 --> 00:45:51,660

have made a theory for that

1144

00:45:55,309 --> 00:45:54,480

okay so um let me just very quickly show

1145

00:45:58,670 --> 00:45:55,319

you

1146

00:46:00,710 --> 00:45:58,680

um some examples of universality in

1147

00:46:02,569 --> 00:46:00,720

Modern Biology even today there are

1148

00:46:04,309 --> 00:46:02,579

things that are Universal not just the

1149

00:46:05,510 --> 00:46:04,319

evolutionary processes of say the

1150

00:46:07,910 --> 00:46:05,520

genetic code which may have happened

1151
00:46:10,849 --> 00:46:07,920
billions of years ago but other things

1152
00:46:12,770 --> 00:46:10,859
too so one example of this is the

1153
00:46:15,290 --> 00:46:12,780
universal statistics of gene expression

1154
00:46:18,109 --> 00:46:15,300
so if I have a genetically identical

1155
00:46:19,910 --> 00:46:18,119
cells they can exhibit different protein

1156
00:46:21,770 --> 00:46:19,920
copy numbers that's something that we've

1157
00:46:23,870 --> 00:46:21,780
known for about 20 years that's called

1158
00:46:26,210 --> 00:46:23,880
stochastic gene expression the whole

1159
00:46:28,970 --> 00:46:26,220
process of of expressing genes is a

1160
00:46:31,670 --> 00:46:28,980
random process and so the protein copy

1161
00:46:34,069 --> 00:46:31,680
numbers are not thermodynamically large

1162
00:46:36,770 --> 00:46:34,079
and so what happens is you have large

1163
00:46:39,349 --> 00:46:36,780

fluctuations in protein copy numbers in

1164

00:46:41,630 --> 00:46:39,359

in cells and here are experimental data

1165

00:46:45,109 --> 00:46:41,640

are showing you for a variety of

1166

00:46:46,609 --> 00:46:45,119

different uh of different uh cells here

1167

00:46:48,650 --> 00:46:46,619

I'm looking to go through the through

1168

00:46:51,710 --> 00:46:48,660

the details showing you that there's a

1169

00:46:54,050 --> 00:46:51,720

universal distribution for the protein

1170

00:46:55,790 --> 00:46:54,060

copy number now which is all these data

1171

00:46:58,730 --> 00:46:55,800

are collapsing onto one universal curve

1172

00:47:01,250 --> 00:46:58,740

can be predicted this is very much like

1173

00:47:02,809 --> 00:47:01,260

the universality I showed you in the

1174

00:47:05,030 --> 00:47:02,819

magnetic system at the beginning of the

1175

00:47:08,690 --> 00:47:06,349

um here's another one which is

1176

00:47:10,849 --> 00:47:08,700

absolutely fantastic and is still not

1177

00:47:13,609 --> 00:47:10,859

understood and that is universal

1178

00:47:15,589 --> 00:47:13,619

metabolism so here's the experiment so

1179

00:47:17,690 --> 00:47:15,599

what you do is you go into the lab and

1180

00:47:19,430 --> 00:47:17,700

uh you get some paper and some mud and

1181

00:47:21,770 --> 00:47:19,440

bits of egg and water and stuff like

1182

00:47:23,210 --> 00:47:21,780

this and you throw in some microbes and

1183

00:47:25,010 --> 00:47:23,220

then you make a bioreactor and the

1184

00:47:27,770 --> 00:47:25,020

bioreactor is producing that same

1185

00:47:31,849 --> 00:47:27,780

methane okay and so you get this thing

1186

00:47:34,430 --> 00:47:31,859

running and the bioreactor is uh your

1187

00:47:36,950 --> 00:47:34,440

measuring is producing a fixed rate of

1188

00:47:39,589 --> 00:47:36,960

methane coming out if you're feeding the

1189

00:47:42,410 --> 00:47:39,599

bioreactor and the rate of uh methane

1190

00:47:45,109 --> 00:47:42,420

coming out is a constant so you say well

1191

00:47:47,089 --> 00:47:45,119

that's great I wonder what's in my

1192

00:47:50,390 --> 00:47:47,099

bioreactor what's in my chemostat

1193

00:47:54,349 --> 00:47:50,400

so you go and do a Melody genomic survey

1194

00:47:56,990 --> 00:47:54,359

and and what you find is that even

1195

00:47:58,370 --> 00:47:57,000

though the methane that is coming out is

1196

00:48:01,010 --> 00:47:58,380

constant

1197

00:48:02,990 --> 00:48:01,020

when you look at the community structure

1198

00:48:05,569 --> 00:48:03,000

that you see and here I'm showing you

1199

00:48:08,990 --> 00:48:05,579

examples these are real data from from

1200

00:48:11,690 --> 00:48:09,000

different uh from a reactor what do you

1201

00:48:14,510 --> 00:48:11,700

find is that you know let's say day 900

1202

00:48:17,089 --> 00:48:14,520

you go and draw a pie chart showing you

1203

00:48:19,430 --> 00:48:17,099

the different uh uh operational

1204

00:48:21,470 --> 00:48:19,440

taxonomic units that are present in your

1205

00:48:24,410 --> 00:48:21,480

system and you say now until I'm done

1206

00:48:26,210 --> 00:48:24,420

and then you know your advisor says aha

1207

00:48:28,010 --> 00:48:26,220

you're not done wait two years and do

1208

00:48:29,210 --> 00:48:28,020

the experiment again so you've trigger

1209

00:48:30,890 --> 00:48:29,220

your thumb for two years and do the

1210

00:48:33,349 --> 00:48:30,900

experiment again and then what you find

1211

00:48:35,809 --> 00:48:33,359

is a completely different uh set of

1212

00:48:37,870 --> 00:48:35,819

organisms that are in the back in the

1213

00:48:40,370 --> 00:48:37,880

bioreactor but they're still producing

1214

00:48:41,270 --> 00:48:40,380

methane is exactly the rate that it was

1215

00:48:43,490 --> 00:48:41,280

before

1216

00:48:48,109 --> 00:48:43,500

hey this experiment was actually done by

1217

00:48:51,530 --> 00:48:48,119

Anna Fernandez and uh and in 1999 and

1218

00:48:54,650 --> 00:48:51,540

her advisor basically said this can't be

1219

00:48:56,150 --> 00:48:54,660

true we can't publish this the the we

1220

00:48:58,670 --> 00:48:56,160

can't publish these data but they

1221

00:49:01,910 --> 00:48:58,680

publish it in any case and and this has

1222

00:49:03,530 --> 00:49:01,920

been replicated many times since so what

1223

00:49:06,710 --> 00:49:03,540

we've learned then is that the

1224

00:49:09,710 --> 00:49:06,720

functional properties of a community are

1225

00:49:12,589 --> 00:49:09,720

insensitive to taxonomic fluctuations

1226

00:49:17,930 --> 00:49:12,599

here's a here's another example this is

1227

00:49:21,050 --> 00:49:17,940

from uh Luca and and durably uh and uh

1228

00:49:23,329 --> 00:49:21,060

partly uh this is decoupling function

1229

00:49:25,730 --> 00:49:23,339

and taxonomy in the global ocean

1230

00:49:28,270 --> 00:49:25,740

microbiome and basically the same the

1231

00:49:30,470 --> 00:49:28,280

same story but despite the constant

1232

00:49:33,530 --> 00:49:30,480

metabolic function of the ocean

1233

00:49:35,569 --> 00:49:33,540

microbiome there were large taxonomic

1234

00:49:38,569 --> 00:49:35,579

fluctuations and we don't have any idea

1235

00:49:40,910 --> 00:49:38,579

of why this is happening

1236

00:49:42,589 --> 00:49:40,920

okay so these are examples of universal

1237

00:49:44,210 --> 00:49:42,599

things that are going on right now and

1238

00:49:45,170 --> 00:49:44,220

they need to be understood and they're

1239

00:49:47,089 --> 00:49:45,180

telling us something about the

1240

00:49:49,190 --> 00:49:47,099

collective properties of microbial

1241

00:49:51,410 --> 00:49:49,200

communities now

1242

00:49:53,930 --> 00:49:51,420

if the NASA astral Biology Institute was

1243

00:49:55,849 --> 00:49:53,940

still still a thing in existence and I

1244

00:49:57,349 --> 00:49:55,859

hadn't moved from Illinois to hear and

1245

00:49:59,089 --> 00:49:57,359

so on one of the things that I would be

1246

00:50:01,550 --> 00:49:59,099

thinking about doing is exploiting this

1247

00:50:03,470 --> 00:50:01,560

for example suppose I want to know what

1248

00:50:07,430 --> 00:50:03,480

are going to be the bio signatures of

1249

00:50:09,650 --> 00:50:07,440

say life that lives under the uh the ice

1250

00:50:12,410 --> 00:50:09,660

of encelados

1251

00:50:14,210 --> 00:50:12,420

well it turns out

1252

00:50:16,130 --> 00:50:14,220

that the metabolic output of microbial

1253

00:50:18,589 --> 00:50:16,140

communities doesn't depend sensitively

1254

00:50:21,050 --> 00:50:18,599

on what organisms are there so if I have

1255

00:50:23,809 --> 00:50:21,060

some knowledge of the geochemistry I can

1256

00:50:25,670 --> 00:50:23,819

then exploit this this uh this

1257

00:50:28,750 --> 00:50:25,680

functional redundancy to be able to make

1258

00:50:31,370 --> 00:50:28,760

predictions about what a metabolic

1259

00:50:33,710 --> 00:50:31,380

biosignatures I might find

1260

00:50:36,349 --> 00:50:33,720

okay so let's end with a discussing

1261

00:50:42,890 --> 00:50:36,359

about whether or not a universality is

1262

00:50:47,150 --> 00:50:45,829

so here is an example of another uh

1263

00:50:55,490 --> 00:50:47,160

scaling law

1264

00:50:58,549 --> 00:50:55,500

been known since the 1850s in England uh

1265

00:51:00,650 --> 00:50:58,559

these are data taken from bird

1266

00:51:03,250 --> 00:51:00,660

lovers actually not bird lovers these

1267

00:51:06,410 --> 00:51:03,260

are plants never mind these are plants

1268

00:51:08,870 --> 00:51:06,420

people in England like two things or

1269

00:51:11,270 --> 00:51:08,880

actually three things they like plants

1270

00:51:12,710 --> 00:51:11,280

they're like birds and they like beer or

1271

00:51:14,270 --> 00:51:12,720

like stink any pie or they're like

1272

00:51:15,950 --> 00:51:14,280

football or whatever you want but they

1273

00:51:17,510 --> 00:51:15,960

like plants and they're like and they

1274

00:51:21,890 --> 00:51:17,520

like birds and so there's a lot of data

1275

00:51:23,510 --> 00:51:21,900

going back uh you know 150 years

1276

00:51:26,329 --> 00:51:23,520

um and here is showing you the

1277

00:51:29,270 --> 00:51:26,339

number of species as a function of the

1278

00:51:31,730 --> 00:51:29,280

area of the of the of the habitat and

1279

00:51:34,250 --> 00:51:31,740

what you can see from these data is that

1280

00:51:36,170 --> 00:51:34,260

the number of species uh scales like the

1281

00:51:38,569 --> 00:51:36,180

area to the one quarter power

1282

00:51:40,730 --> 00:51:38,579

so you might say here's a field count

1283

00:51:42,049 --> 00:51:40,740

all the bugs in the field count all the

1284

00:51:44,390 --> 00:51:42,059

plants in the field

1285

00:51:46,190 --> 00:51:44,400

double the size of the field count how

1286

00:51:47,569 --> 00:51:46,200

many they're in there then you might say

1287

00:51:50,329 --> 00:51:47,579

okay remember species are going to

1288

00:51:53,210 --> 00:51:50,339

double not true it goes like roughly

1289

00:51:56,089 --> 00:51:53,220

like the area to the one quarter power

1290

00:51:59,210 --> 00:51:56,099

not not the area itself so this is a

1291

00:52:02,329 --> 00:51:59,220

very important law because we can use it

1292

00:52:05,210 --> 00:52:02,339

to make extrapolations for example if we

1293

00:52:08,030 --> 00:52:05,220

know how much deforestation happened

1294

00:52:09,470 --> 00:52:08,040

today in the Amazon let's say when we

1295

00:52:12,890 --> 00:52:09,480

can figure out how many species might

1296

00:52:16,190 --> 00:52:12,900

have got uh affected by that

1297

00:52:17,990 --> 00:52:16,200

so that says these universal laws are

1298

00:52:19,790 --> 00:52:18,000

useful there's an argument that says

1299

00:52:21,530 --> 00:52:19,800

they're not useful

1300

00:52:23,329 --> 00:52:21,540

so here's an experiment that was

1301
00:52:24,670 --> 00:52:23,339
actually done this is Battle at Colorado

1302
00:52:28,849 --> 00:52:24,680
Island

1303
00:52:31,190 --> 00:52:28,859
in Panama and this is a an island which

1304
00:52:33,829 --> 00:52:31,200
is beloved by ecologists because it has

1305
00:52:35,450 --> 00:52:33,839
lots of trees and plants and we know

1306
00:52:38,089 --> 00:52:35,460
every single tree and every plant on

1307
00:52:39,890 --> 00:52:38,099
that island it's heavily studded okay

1308
00:52:42,710 --> 00:52:39,900
so you might ask yourself the following

1309
00:52:44,630 --> 00:52:42,720
question on this island what is the

1310
00:52:47,030 --> 00:52:44,640
number of species fraction of species

1311
00:52:49,549 --> 00:52:47,040
with a given number of individuals okay

1312
00:52:51,170 --> 00:52:49,559
how many species have 100 individuals

1313
00:52:52,609 --> 00:52:51,180

how many species have a thousand

1314

00:52:55,069 --> 00:52:52,619

individuals how many species have four

1315

00:52:59,450 --> 00:52:55,079

individuals in salt okay so you can

1316

00:53:02,210 --> 00:52:59,460

produce a species abundance curve and um

1317

00:53:03,589 --> 00:53:02,220

and then you and you get data that looks

1318

00:53:05,569 --> 00:53:03,599

like one of these curves here I don't

1319

00:53:07,849 --> 00:53:05,579

even remember which one it is so that

1320

00:53:09,589 --> 00:53:07,859

would be uh that would be a measurement

1321

00:53:11,450 --> 00:53:09,599

and you could make a theory for that

1322

00:53:13,430 --> 00:53:11,460

because you could say well we have to

1323

00:53:14,690 --> 00:53:13,440

look at the soil we have to look at the

1324

00:53:16,309 --> 00:53:14,700

weather we have to look at the

1325

00:53:18,410 --> 00:53:16,319

interactions between the trees the

1326

00:53:20,630 --> 00:53:18,420

canopy and so on and so forth and if we

1327

00:53:24,290 --> 00:53:20,640

had a detailed model we could probably

1328

00:53:25,790 --> 00:53:24,300

predict uh this this this curve

1329

00:53:28,069 --> 00:53:25,800

but there's another way to think about

1330

00:53:29,450 --> 00:53:28,079

it which is just to say well let's just

1331

00:53:31,430 --> 00:53:29,460

close it's just a random process

1332

00:53:34,130 --> 00:53:31,440

something has to be the most abundant

1333

00:53:36,770 --> 00:53:34,140

organism okay so what I've read is

1334

00:53:38,150 --> 00:53:36,780

that's it what its name is but then

1335

00:53:40,130 --> 00:53:38,160

something else has to be the next most

1336

00:53:41,809 --> 00:53:40,140

abundant and you can work out a theory

1337

00:53:44,150 --> 00:53:41,819

that looks like the general statistics

1338

00:53:46,370 --> 00:53:44,160

that you would expect for abundance just

1339

00:53:47,690 --> 00:53:46,380

like the central limit theorem in in

1340

00:53:50,510 --> 00:53:47,700

statistics

1341

00:53:52,069 --> 00:53:50,520

and so in in a neutral Theory the

1342

00:53:54,230 --> 00:53:52,079

species are functionally equivalent

1343

00:53:56,630 --> 00:53:54,240

they're not different they don't occupy

1344

00:53:58,970 --> 00:53:56,640

different uh geochemical or biological

1345

00:54:01,910 --> 00:53:58,980

niches metabolic niches so you've got

1346

00:54:04,250 --> 00:54:01,920

these two completely different theories

1347

00:54:05,750 --> 00:54:04,260

and one of them gives the black curve

1348

00:54:08,150 --> 00:54:05,760

one of them gives the green curve they

1349

00:54:10,609 --> 00:54:08,160

both explain the data equally well

1350

00:54:13,309 --> 00:54:10,619

so this is uh again

1351

00:54:15,470 --> 00:54:13,319

not not helpful so the upside of

1352

00:54:17,089 --> 00:54:15,480

universality is that you can make

1353

00:54:18,650 --> 00:54:17,099

predictions based on the minimal model

1354

00:54:21,230 --> 00:54:18,660

and that's a good thing

1355

00:54:23,450 --> 00:54:21,240

like trying to predict the metabolic

1356

00:54:26,569 --> 00:54:23,460

signature or putative life under the

1357

00:54:28,849 --> 00:54:26,579

under the ice cap of encels the downside

1358

00:54:30,890 --> 00:54:28,859

of universality is that statistically

1359

00:54:32,870 --> 00:54:30,900

similar results can be obtained from

1360

00:54:34,609 --> 00:54:32,880

microscopic models that are completely

1361

00:54:36,410 --> 00:54:34,619

different in their assumptions

1362

00:54:38,690 --> 00:54:36,420

and so if you have something Universal

1363

00:54:40,370 --> 00:54:38,700

at a high level of description that

1364

00:54:43,069 --> 00:54:40,380

means you can't understand the actual

1365

00:54:45,349 --> 00:54:43,079

processes that went on that caused the

1366

00:54:48,770 --> 00:54:45,359

thing in the first place

1367

00:54:50,870 --> 00:54:48,780

okay I want to end by asking what do we

1368

00:54:53,990 --> 00:54:50,880

miss if we don't understand Universal

1369

00:54:56,809 --> 00:54:54,000

phenomena and I'm going to talk about an

1370

00:54:59,089 --> 00:54:56,819

example uh that that may not be

1371

00:55:01,250 --> 00:54:59,099

meaningful to to some of you or many of

1372

00:55:04,069 --> 00:55:01,260

you even but it doesn't matter I want

1373

00:55:05,510 --> 00:55:04,079

you to just understand the the point so

1374

00:55:08,450 --> 00:55:05,520

this is about something in in

1375

00:55:10,730 --> 00:55:08,460

superconductivity and uh and there's a

1376

00:55:12,530 --> 00:55:10,740

couple of students here from my class on

1377

00:55:14,690 --> 00:55:12,540

emerging states of matter so they'll be

1378

00:55:17,270 --> 00:55:14,700

familiar with these examples so what is

1379

00:55:20,150 --> 00:55:17,280

superconductivity it's the it's the fact

1380

00:55:21,829 --> 00:55:20,160

that you can have a current flowing

1381

00:55:23,750 --> 00:55:21,839

through a material and there is no

1382

00:55:26,030 --> 00:55:23,760

electrical resistance and no heat that

1383

00:55:28,130 --> 00:55:26,040

comes out so that's that's the that's

1384

00:55:29,990 --> 00:55:28,140

the idea of superconductivity it's just

1385

00:55:32,870 --> 00:55:30,000

superconductor if you have it you can

1386

00:55:35,210 --> 00:55:32,880

make levitating trains and and transmit

1387

00:55:37,130 --> 00:55:35,220

power over long distances and solve all

1388

00:55:39,849 --> 00:55:37,140

the world's problems

1389

00:55:43,849 --> 00:55:39,859

that was discovered in 1911

1390

00:55:46,130 --> 00:55:43,859

1903 1933 it was also discovered that

1391

00:55:48,890 --> 00:55:46,140

superconductors don't just have a a

1392

00:55:50,690 --> 00:55:48,900

current that lasts forever and also go

1393

00:55:53,329 --> 00:55:50,700

round and round Forever by petrol motion

1394

00:55:56,150 --> 00:55:53,339

they also expel magnetic fields okay

1395

00:55:58,549 --> 00:55:56,160

don't ask why it doesn't matter

1396

00:55:59,990 --> 00:55:58,559

20 years later after that it was

1397

00:56:01,490 --> 00:56:00,000

discovered that actually nope it's not

1398

00:56:04,010 --> 00:56:01,500

true they don't expel magnetic fields

1399

00:56:06,230 --> 00:56:04,020

well some do but some don't some allow

1400

00:56:08,990 --> 00:56:06,240

magnetic fields to penetrate a

1401
00:56:11,329 --> 00:56:09,000
superconductor but in a lattice of

1402
00:56:12,410 --> 00:56:11,339
so-called vortices or flux tubes in a

1403
00:56:14,150 --> 00:56:12,420
way that is

1404
00:56:16,490 --> 00:56:14,160
you know I'm not going to I'm not going

1405
00:56:19,069 --> 00:56:16,500
to go into but that that can happen and

1406
00:56:21,650 --> 00:56:19,079
then finally oops wrong thing then

1407
00:56:24,109 --> 00:56:21,660
finally uh about 10 years or so after

1408
00:56:26,690 --> 00:56:24,119
that something called the judicial

1409
00:56:27,770 --> 00:56:26,700
effect was discovered the idea that I

1410
00:56:30,890 --> 00:56:27,780
can have

1411
00:56:34,190 --> 00:56:30,900
um a current uh flowing

1412
00:56:36,349 --> 00:56:34,200
um which which will will be uh um

1413
00:56:39,410 --> 00:56:36,359

oscillating with a frequency that is

1414

00:56:41,089 --> 00:56:39,420

just determined by quantum mechanics and

1415

00:56:43,010 --> 00:56:41,099

doesn't depend on the material or

1416

00:56:46,250 --> 00:56:43,020

anything like that so you can use this

1417

00:56:48,710 --> 00:56:46,260

to create a universal standard of

1418

00:56:50,930 --> 00:56:48,720

voltage and and of time okay so this

1419

00:56:53,809 --> 00:56:50,940

this is a complicated quantum mechanical

1420

00:56:56,510 --> 00:56:53,819

effect and it took 50 years and and most

1421

00:56:57,890 --> 00:56:56,520

of the people on on this who discovered

1422

00:56:59,630 --> 00:56:57,900

these things ends up getting Nobel

1423

00:57:01,910 --> 00:56:59,640

prizes these were very important things

1424

00:57:04,130 --> 00:57:01,920

scientifically and technically and the

1425

00:57:05,510 --> 00:57:04,140

question is why did it take so long to

1426
00:57:08,569 --> 00:57:05,520
make these discoveries are physicists

1427
00:57:10,609 --> 00:57:08,579
stupid well maybe but uh but the thing

1428
00:57:13,250 --> 00:57:10,619
is this it's even worse because in my

1429
00:57:15,230 --> 00:57:13,260
class I derive all of these things in in

1430
00:57:16,750 --> 00:57:15,240
basically one lecture in a few lines of

1431
00:57:20,030 --> 00:57:16,760
algebra for

1432
00:57:22,430 --> 00:57:20,040
jumbo that's written down here okay so

1433
00:57:24,829 --> 00:57:22,440
what was going wrong what was going

1434
00:57:28,130 --> 00:57:24,839
wrong was that people were focusing on

1435
00:57:29,390 --> 00:57:28,140
the wrong level of description and I

1436
00:57:30,829 --> 00:57:29,400
want to explain to you what I mean by

1437
00:57:34,250 --> 00:57:30,839
that

1438
00:57:36,230 --> 00:57:34,260

okay so in world of superconductivity

1439

00:57:37,670 --> 00:57:36,240

you have to make a superconductor so

1440

00:57:39,950 --> 00:57:37,680

that's a problem in quantum chemistry

1441

00:57:42,950 --> 00:57:39,960

and Material Science there's a theory

1442

00:57:45,230 --> 00:57:42,960

that applies to at least the classic

1443

00:57:46,730 --> 00:57:45,240

superconductors but not the ones that

1444

00:57:48,530 --> 00:57:46,740

everybody's excited about for the last

1445

00:57:50,630 --> 00:57:48,540

30 years the high temperature

1446

00:57:52,490 --> 00:57:50,640

superconductors so there's a theory of

1447

00:57:54,410 --> 00:57:52,500

that which is which is very nice and so

1448

00:57:56,630 --> 00:57:54,420

on and then lastly there's a theory

1449

00:57:59,089 --> 00:57:56,640

which I which I've given by this name

1450

00:58:01,730 --> 00:57:59,099

here is basically a theory that looks at

1451
00:58:04,190 --> 00:58:01,740
the quantum mechanical symmetries of

1452
00:58:07,490 --> 00:58:04,200
Superman actors now when we talk about

1453
00:58:10,549 --> 00:58:07,500
biology we have another set of levels of

1454
00:58:12,530 --> 00:58:10,559
description so so this level is quantum

1455
00:58:14,630 --> 00:58:12,540
chemistry this is electrons moving

1456
00:58:17,930 --> 00:58:14,640
around and this is looking at Symmetry

1457
00:58:19,790 --> 00:58:17,940
and and wave functions all right here in

1458
00:58:21,349 --> 00:58:19,800
biology we start off with the lowest

1459
00:58:22,370 --> 00:58:21,359
level of description with atoms and

1460
00:58:23,809 --> 00:58:22,380
molecules

1461
00:58:25,790 --> 00:58:23,819
there's an intermediate level of

1462
00:58:27,470 --> 00:58:25,800
description where we you know we talked

1463
00:58:29,750 --> 00:58:27,480

about with translation we look at our

1464

00:58:31,609 --> 00:58:29,760

DNA we look at how elastic it is and how

1465

00:58:33,410 --> 00:58:31,619

proteins fold and things like this we

1466

00:58:35,390 --> 00:58:33,420

look at a liquid liquid intracellular

1467

00:58:36,410 --> 00:58:35,400

complexes and things like that in cell

1468

00:58:38,809 --> 00:58:36,420

biology

1469

00:58:41,750 --> 00:58:38,819

and then finally on the LA on the larger

1470

00:58:43,789 --> 00:58:41,760

scale I talked about the Dynamics of how

1471

00:58:46,130 --> 00:58:43,799

systems evolved the Dynamics of evolving

1472

00:58:48,710 --> 00:58:46,140

systems like the genetic code

1473

00:58:50,930 --> 00:58:48,720

so those are levels of description these

1474

00:58:54,589 --> 00:58:50,940

levels of description answer different

1475

00:58:56,690 --> 00:58:54,599

questions so in superconductivity well

1476
00:58:59,809 --> 00:58:56,700
quantum chemistry of Material Science

1477
00:59:01,730 --> 00:58:59,819
says how do you make a stuff what's the

1478
00:59:03,349 --> 00:59:01,740
specific recipe of putting the atoms

1479
00:59:05,329 --> 00:59:03,359
together in such a way that you make a

1480
00:59:08,089 --> 00:59:05,339
particular superconductor

1481
00:59:10,789 --> 00:59:08,099
this uh this uh this intermediate level

1482
00:59:13,789 --> 00:59:10,799
of description tells you about what is

1483
00:59:15,410 --> 00:59:13,799
the basic mechanism by which uh you know

1484
00:59:17,150 --> 00:59:15,420
electrons form what's called a Cooper

1485
00:59:18,589 --> 00:59:17,160
pair a composite bows on the inside a

1486
00:59:20,809 --> 00:59:18,599
superconductor and then do something

1487
00:59:23,390 --> 00:59:20,819
called Bose condensation so this is a

1488
00:59:25,309 --> 00:59:23,400

sort of more detailed uh description

1489

00:59:27,710 --> 00:59:25,319

that applies to um to many different

1490

00:59:30,170 --> 00:59:27,720

superconductors and this level of

1491

00:59:32,990 --> 00:59:30,180

description this symmetry wave function

1492

00:59:34,430 --> 00:59:33,000

quantum mechanical Theory describes why

1493

00:59:36,710 --> 00:59:34,440

the phenomenon of superconductivity

1494

00:59:38,630 --> 00:59:36,720

exists at all how you can get all the

1495

00:59:40,789 --> 00:59:38,640

phenomenon of superconductivity just

1496

00:59:42,289 --> 00:59:40,799

from one very simple and mathematical

1497

00:59:45,470 --> 00:59:42,299

description

1498

00:59:47,329 --> 00:59:45,480

now in the in the world of biology atoms

1499

00:59:50,870 --> 00:59:47,339

and molecules tells us something about

1500

00:59:53,030 --> 00:59:50,880

how specific biopolymers interact and

1501
00:59:54,829 --> 00:59:53,040
fold undergo template-directed synthesis

1502
00:59:56,510 --> 00:59:54,839
and so on and so forth if you want to

1503
00:59:58,130 --> 00:59:56,520
understand those questions you have to

1504
00:59:59,390 --> 00:59:58,140
deal with atoms and molecules there's no

1505
01:00:01,670 --> 00:59:59,400
way around it

1506
01:00:03,589 --> 01:00:01,680
if you want to understand

1507
01:00:05,870 --> 01:00:03,599
um the you know the basic functional

1508
01:00:08,150 --> 01:00:05,880
cellular processes you don't need to

1509
01:00:10,730 --> 01:00:08,160
have such a detailed description you can

1510
01:00:13,250 --> 01:00:10,740
just think about uh you know face

1511
01:00:15,289 --> 01:00:13,260
separation inside cells and and sort of

1512
01:00:17,390 --> 01:00:15,299
bending rigidity of cell membranes and

1513
01:00:19,490 --> 01:00:17,400

DNA and so on and so forth

1514

01:00:21,770 --> 01:00:19,500

and if you want to understand why the

1515

01:00:23,630 --> 01:00:21,780

phenomenon of Life exists at all well

1516

01:00:25,849 --> 01:00:23,640

that's surely a question that would be

1517

01:00:28,609 --> 01:00:25,859

answered if we understood more about the

1518

01:00:31,730 --> 01:00:28,619

Dynamics of evolving systems

1519

01:00:34,490 --> 01:00:31,740

different levels of description apply to

1520

01:00:36,890 --> 01:00:34,500

different levels of universality so if I

1521

01:00:38,750 --> 01:00:36,900

look in in the quantum chemistry of

1522

01:00:40,430 --> 01:00:38,760

material science that tells us something

1523

01:00:42,109 --> 01:00:40,440

about very specific materials like

1524

01:00:44,390 --> 01:00:42,119

Atrium barium and copper oxide or

1525

01:00:46,549 --> 01:00:44,400

something like this if I want to look at

1526

01:00:48,289 --> 01:00:46,559

this level of description it tells us

1527

01:00:50,569 --> 01:00:48,299

something about what are called weak

1528

01:00:53,270 --> 01:00:50,579

coupling superconductors and finally

1529

01:00:55,549 --> 01:00:53,280

this level of description uh this

1530

01:00:57,470 --> 01:00:55,559

symmetry wave function Theory tells us

1531

01:00:59,450 --> 01:00:57,480

about all superconductors whether

1532

01:01:01,730 --> 01:00:59,460

they're made in a material science lab

1533

01:01:05,150 --> 01:01:01,740

or whether they occur in the in the

1534

01:01:08,049 --> 01:01:05,160

heart of a of a neutron star

1535

01:01:11,510 --> 01:01:08,059

in biology this level of description

1536

01:01:13,250 --> 01:01:11,520

applies effort to uh very specific

1537

01:01:15,710 --> 01:01:13,260

biopolymers you know those chemical

1538

01:01:17,349 --> 01:01:15,720

structure of RNA or DNA or some

1539

01:01:21,349 --> 01:01:17,359

particular protein

1540

01:01:23,089 --> 01:01:21,359

the elasticity theory for DNA and so on

1541

01:01:26,510 --> 01:01:23,099

and so forth tells you about the physics

1542

01:01:28,130 --> 01:01:26,520

of subcellular components and the

1543

01:01:30,470 --> 01:01:28,140

Dynamics of evolving systems would have

1544

01:01:32,809 --> 01:01:30,480

would be applying to all life and just

1545

01:01:34,370 --> 01:01:32,819

in the same way that a universal turing

1546

01:01:36,289 --> 01:01:34,380

machine with a Von Neumann architecture

1547

01:01:38,450 --> 01:01:36,299

applies to all things that we call

1548

01:01:40,970 --> 01:01:38,460

computers

1549

01:01:44,390 --> 01:01:40,980

now why do we need this Universal level

1550

01:01:47,390 --> 01:01:44,400

this top level description of of of of

1551

01:01:50,390 --> 01:01:47,400

stuff well if I have a superconductor

1552

01:01:52,490 --> 01:01:50,400

and I want to understand uh this level

1553

01:01:54,650 --> 01:01:52,500

of description not only does it tell me

1554

01:01:55,849 --> 01:01:54,660

that superconductors exist but it also

1555

01:01:58,069 --> 01:01:55,859

tells me everything that a

1556

01:01:59,870 --> 01:01:58,079

superconductor can do it tells me the

1557

01:02:02,450 --> 01:01:59,880

myosin effect the vortex lattice the

1558

01:02:03,770 --> 01:02:02,460

josen effects it tells me how a

1559

01:02:06,410 --> 01:02:03,780

superconductor responds to

1560

01:02:08,089 --> 01:02:06,420

electromagnetic fields so if I don't

1561

01:02:10,130 --> 01:02:08,099

have this

1562

01:02:12,049 --> 01:02:10,140

I can't predict how a superconductor

1563

01:02:15,289 --> 01:02:12,059

responds to an electromagnetic field and

1564

01:02:19,250 --> 01:02:17,270

by regarding superconductors as

1565

01:02:21,710 --> 01:02:19,260

collections of atoms

1566

01:02:23,809 --> 01:02:21,720

we are missing the emergent laws that

1567

01:02:25,670 --> 01:02:23,819

act at the system scale and govern the

1568

01:02:28,549 --> 01:02:25,680

large-scale response to electromagnetic

1569

01:02:31,190 --> 01:02:28,559

fields just like

1570

01:02:34,130 --> 01:02:31,200

when we were looking at our bioreactor

1571

01:02:37,549 --> 01:02:34,140

it produces methane at a constant rate

1572

01:02:39,410 --> 01:02:37,559

if we just focus on the on the on the uh

1573

01:02:41,329 --> 01:02:39,420

on the bacteria that are in there we

1574

01:02:43,069 --> 01:02:41,339

won't be able to understand that we need

1575

01:02:46,010 --> 01:02:43,079

to understand how metabolism can be

1576
01:02:47,930 --> 01:02:46,020
emergent in a community this problem we

1577
01:02:49,970 --> 01:02:47,940
know how to solve it took us 50 years to

1578
01:02:51,289 --> 01:02:49,980
do it and we had to rejigger the way we

1579
01:02:54,230 --> 01:02:51,299
think about physics

1580
01:02:56,210 --> 01:02:54,240
for living systems we know that this

1581
01:02:58,309 --> 01:02:56,220
level of description would apply to all

1582
01:03:00,950 --> 01:02:58,319
of life and what happens if we don't

1583
01:03:02,450 --> 01:03:00,960
have it we can't predict the response of

1584
01:03:04,730 --> 01:03:02,460
living systems to selective

1585
01:03:07,430 --> 01:03:04,740
perturbations we can't tell what happens

1586
01:03:09,770 --> 01:03:07,440
when you play antibiotics or herbicides

1587
01:03:12,950 --> 01:03:09,780
or insecticides or chemotherapy to

1588
01:03:14,210 --> 01:03:12,960

somebody with cancer okay and and we

1589

01:03:16,849 --> 01:03:14,220

know what happens in the real world

1590

01:03:18,650 --> 01:03:16,859

whenever we do these interventions and

1591

01:03:19,910 --> 01:03:18,660

treat living systems as engineered

1592

01:03:22,309 --> 01:03:19,920

systems

1593

01:03:24,890 --> 01:03:22,319

what happens is they fight back they

1594

01:03:26,630 --> 01:03:24,900

evolve the cancer tumor evolves and you

1595

01:03:29,329 --> 01:03:26,640

and you and you and the chemotherapy

1596

01:03:30,789 --> 01:03:29,339

stops being effective Roundup stops

1597

01:03:32,930 --> 01:03:30,799

being effective against weeds

1598

01:03:35,089 --> 01:03:32,940

antibiotics stop being effective against

1599

01:03:36,530 --> 01:03:35,099

bacterial infections and so on and so

1600

01:03:38,569 --> 01:03:36,540

forth

1601
01:03:40,849 --> 01:03:38,579
by regarding biology as complicated

1602
01:03:42,230 --> 01:03:40,859
physical systems we are missing the

1603
01:03:44,150 --> 01:03:42,240
emerging laws that act on the system

1604
01:03:46,549 --> 01:03:44,160
scale and govern the large-scale

1605
01:03:51,049 --> 01:03:46,559
response to control perturbations and we

1606
01:03:54,230 --> 01:03:52,849
all right if you if you want to read

1607
01:03:56,589 --> 01:03:54,240
about any of these things that I've been

1608
01:03:59,990 --> 01:03:56,599
talking about there is a article I wrote

1609
01:04:02,450 --> 01:04:00,000
uh called life is physics with uh with

1610
01:04:04,789 --> 01:04:02,460
Carl was and another one on the

1611
01:04:08,210 --> 01:04:04,799
statistical mechanics of early life in

1612
01:04:10,549 --> 01:04:08,220
Phil transa this one was called life is

1613
01:04:12,230 --> 01:04:10,559

physics for the following reason

1614

01:04:14,690 --> 01:04:12,240

when I used to go to astrobiology

1615

01:04:16,490 --> 01:04:14,700

conferences on the first day somebody

1616

01:04:19,190 --> 01:04:16,500

would get up and show some extremely

1617

01:04:21,170 --> 01:04:19,200

complicated chemical pathway that they

1618

01:04:23,390 --> 01:04:21,180

thought might have existed in the RNA

1619

01:04:25,430 --> 01:04:23,400

world or the sugar world or lipid world

1620

01:04:27,349 --> 01:04:25,440

or whatever will be was the fat all the

1621

01:04:28,670 --> 01:04:27,359

time and they would say life is

1622

01:04:32,990 --> 01:04:28,680

chemistry

1623

01:04:34,250 --> 01:04:33,000

doesn't it doesn't matter it does matter

1624

01:04:36,109 --> 01:04:34,260

you can't build a superconductor with

1625

01:04:37,910 --> 01:04:36,119

our atoms and molecules but you have to

1626
01:04:40,549 --> 01:04:37,920
understand the emergent physical laws as

1627
01:04:42,530 --> 01:04:40,559
well the dynamical processes that go on

1628
01:04:44,690 --> 01:04:42,540
and so that's why we talk about this as

1629
01:04:46,670 --> 01:04:44,700
life as physics

1630
01:04:48,650 --> 01:04:46,680
all right so did we learn new physics

1631
01:04:51,890 --> 01:04:48,660
when we study biological biological

1632
01:04:53,210 --> 01:04:51,900
systems uh yes we do we we realize that

1633
01:04:55,609 --> 01:04:53,220
they actually do things that physical

1634
01:04:58,390 --> 01:04:55,619
systems don't are they Universal

1635
01:05:00,770 --> 01:04:58,400
phenomena in biology yes genetic code

1636
01:05:03,289 --> 01:05:00,780
gene expression distribution of species

1637
01:05:05,569 --> 01:05:03,299
metabolism and so on do they reveal

1638
01:05:07,789 --> 01:05:05,579

things that are important well yes they

1639

01:05:09,470 --> 01:05:07,799

tell us about the phase diagram of life

1640

01:05:11,690 --> 01:05:09,480

because about cell structure and

1641

01:05:13,010 --> 01:05:11,700

principles of how things evolve and what

1642

01:05:15,410 --> 01:05:13,020

do we miss by not understanding

1643

01:05:17,870 --> 01:05:15,420

Universal phenomena we've we don't

1644

01:05:19,789 --> 01:05:17,880

understand why life exists at all and we

1645

01:05:23,270 --> 01:05:19,799

don't understand how to how biological

1646

01:05:26,510 --> 01:05:23,280

systems respond to control perturbations

1647

01:05:28,490 --> 01:05:26,520

so so here is uh here is the the history

1648

01:05:30,829 --> 01:05:28,500

of life we know that some around here

1649

01:05:32,990 --> 01:05:30,839

was a homoclimal transition in the

1650

01:05:35,690 --> 01:05:33,000

genetic code the darwinian transition

1651

01:05:38,030 --> 01:05:35,700

and finally 3.8 billion years ago last

1652

01:05:39,829 --> 01:05:38,040

Universal common ancestor all of this

1653

01:05:43,069 --> 01:05:39,839

happens super fast because it was

1654

01:05:45,349 --> 01:05:43,079

dominated by Network effects and while

1655

01:05:48,130 --> 01:05:45,359

and what I didn't tell you about this in

1656

01:05:50,870 --> 01:05:48,140

detail or the catalysis leads to 100

1657

01:05:53,150 --> 01:05:50,880

homicorality horizontal Gene transfer

1658

01:05:55,130 --> 01:05:53,160

networks Drive the evolution of the

1659

01:05:56,750 --> 01:05:55,140

unique optimal genetic code and

1660

01:05:58,789 --> 01:05:56,760

horizontal Gene transfer eventually

1661

01:06:01,309 --> 01:05:58,799

becomes ineffective compared to Vertical

1662

01:06:03,410 --> 01:06:01,319

selection and you get this transition to

1663

01:06:05,450 --> 01:06:03,420

the vertical phase of life that we are

1664

01:06:08,630 --> 01:06:05,460

in today

1665

01:06:11,329 --> 01:06:08,640

I want to end with a quote a since I'm a

1666

01:06:13,789 --> 01:06:11,339

physicist I study biology I'm not

1667

01:06:16,730 --> 01:06:13,799

because I love biology I have a sort of

1668

01:06:19,130 --> 01:06:16,740

hate relationship with Biology but

1669

01:06:21,589 --> 01:06:19,140

but because it teaches me things that

1670

01:06:23,569 --> 01:06:21,599

are that expands the scope of physics so

1671

01:06:25,910 --> 01:06:23,579

ask not what physics can do for biology

1672

01:06:27,950 --> 01:06:25,920

build you a better microscope build your

1673

01:06:31,270 --> 01:06:27,960

build a computer simulation understand

1674

01:06:33,410 --> 01:06:31,280

the uh the structure of some protein

1675

01:06:34,970 --> 01:06:33,420

asking instead of what biology can do

1676
01:06:37,530 --> 01:06:34,980
for physics it can teach us wonderful

1677
01:06:51,130 --> 01:06:37,540
things thank you very much

1678
01:06:51,140 --> 01:06:55,849
all right

1679
01:07:01,010 --> 01:06:58,609
so I'm very recently coming to

1680
01:07:02,809 --> 01:07:01,020
appreciate this the importance of this

1681
01:07:05,230 --> 01:07:02,819
horizontal Gene transfer but

1682
01:07:08,329 --> 01:07:05,240
mechanistically I don't understand

1683
01:07:10,789 --> 01:07:08,339
how like why this trade-off is tied to

1684
01:07:12,190 --> 01:07:10,799
optimizing the genetic code well you

1685
01:07:14,450 --> 01:07:12,200
don't understand why what

1686
01:07:17,510 --> 01:07:14,460
mechanistically I don't understand why

1687
01:07:23,470 --> 01:07:17,520
it's massive Advantage is tied to having

1688
01:07:29,870 --> 01:07:28,010

so the question is uh why why why is if

1689

01:07:32,089 --> 01:07:29,880

I understand why why is horizontal Gene

1690

01:07:34,130 --> 01:07:32,099

transfer

1691

01:07:35,510 --> 01:07:34,140

um important in in evolving these

1692

01:07:38,930 --> 01:07:35,520

genetic code is that what you're asking

1693

01:07:40,670 --> 01:07:38,940

yeah yeah yeah so so the fundamental

1694

01:07:42,470 --> 01:07:40,680

reason is this well I showed you in the

1695

01:07:44,450 --> 01:07:42,480

in the simulations

1696

01:07:47,450 --> 01:07:44,460

um was that if you if you just have

1697

01:07:48,650 --> 01:07:47,460

vertical Evolution which I explained to

1698

01:07:50,029 --> 01:07:48,660

you what it is

1699

01:07:51,470 --> 01:07:50,039

um you kind of get trapped in local

1700

01:07:54,049 --> 01:07:51,480

Minima

1701

01:07:56,270 --> 01:07:54,059

okay so horizontal Gene transfer is a

1702

01:07:58,910 --> 01:07:56,280

very non-local shuffling of genes that

1703

01:08:00,829 --> 01:07:58,920

wouldn't otherwise happen and so it's a

1704

01:08:03,410 --> 01:08:00,839

much faster way of exploring the space

1705

01:08:06,890 --> 01:08:03,420

of possibilities and so what happened in

1706

01:08:10,609 --> 01:08:06,900

early life is organisms were very porous

1707

01:08:12,890 --> 01:08:10,619

there's a lot of endosymbiosis so you

1708

01:08:14,630 --> 01:08:12,900

know today we we only you know you and I

1709

01:08:17,870 --> 01:08:14,640

are not horizontally transferring genes

1710

01:08:20,209 --> 01:08:17,880

the bacteria in our guts are but in

1711

01:08:22,010 --> 01:08:20,219

early life organisms would sort of Pulp

1712

01:08:24,709 --> 01:08:22,020

go through each other and Collide and

1713

01:08:26,329 --> 01:08:24,719

and subsume each other and so on and so

1714

01:08:28,490 --> 01:08:26,339

there was a very natural built-in

1715

01:08:29,990 --> 01:08:28,500

mechanism for genes to be horizontally

1716

01:08:34,130 --> 01:08:30,000

transferred

1717

01:08:36,769 --> 01:08:34,140

and so when we when we model that in our

1718

01:08:38,689 --> 01:08:36,779

in our simulations what we see is that

1719

01:08:40,249 --> 01:08:38,699

is enormously effective in accelerating

1720

01:08:43,189 --> 01:08:40,259

the evolution rate

1721

01:08:44,689 --> 01:08:43,199

so so bottom line is horizontal Gene

1722

01:08:45,890 --> 01:08:44,699

transfer is just one way to accelerate

1723

01:08:47,870 --> 01:08:45,900

evolution

1724

01:08:49,789 --> 01:08:47,880

and if you accelerate Evolution you

1725

01:08:51,410 --> 01:08:49,799

don't get stuck in local Minima if you

1726

01:08:54,229 --> 01:08:51,420

don't get stuck in local minimum as it

1727

01:08:56,510 --> 01:08:54,239

were you'd then find the true

1728

01:08:58,490 --> 01:08:56,520

dust code or the best whatever it is

1729

01:09:00,950 --> 01:08:58,500

that you're optimizing and and that's

1730

01:09:03,349 --> 01:09:00,960

why that's why it works so did I answer

1731

01:09:05,329 --> 01:09:03,359

your question what was the bit what was

1732

01:09:08,570 --> 01:09:05,339

the bit that I hadn't explained that

1733

01:09:12,410 --> 01:09:10,550

I I saw it empirically that it was true

1734

01:09:15,590 --> 01:09:12,420

but the mechanism oh okay so I explained

1735

01:09:19,189 --> 01:09:15,600

it yeah go ahead thank you okay yeah hi

1736

01:09:21,470 --> 01:09:19,199

there hi uh I'm Maddie from um MIT

1737

01:09:23,510 --> 01:09:21,480

um great talk I was kind of interested

1738

01:09:26,390 --> 01:09:23,520

based on your like um idea of evolution

1739

01:09:28,370 --> 01:09:26,400

of this like Pro Geno like horizontal

1740

01:09:30,110 --> 01:09:28,380

Gene transfer dominated system evolving

1741

01:09:31,729 --> 01:09:30,120

to this darwinian phase where do you

1742

01:09:33,650 --> 01:09:31,739

think kind of the universality of like

1743

01:09:34,910 --> 01:09:33,660

essential Dogma kind of starts to evolve

1744

01:09:37,130 --> 01:09:34,920

when we think of like the genetic code

1745

01:09:38,510 --> 01:09:37,140

of like codons to proteins and DNA like

1746

01:09:40,970 --> 01:09:38,520

is that something that might have

1747

01:09:42,470 --> 01:09:40,980

existed with like this pre-state or

1748

01:09:44,570 --> 01:09:42,480

would this be something we only see with

1749

01:09:47,150 --> 01:09:44,580

like the rise of like I don't think the

1750

01:09:49,849 --> 01:09:47,160

central dogma even exists today

1751

01:09:51,709 --> 01:09:49,859

okay we we know we know that that's we

1752

01:09:54,530 --> 01:09:51,719

know that that's not true we know that

1753

01:09:56,270 --> 01:09:54,540

there are there are ways that um that

1754

01:09:58,189 --> 01:09:56,280

there can be you know post-translational

1755

01:10:00,290 --> 01:09:58,199

modifications you have a virtual

1756

01:10:03,950 --> 01:10:00,300

transcription and so on and so forth so

1757

01:10:07,490 --> 01:10:03,960

so organisms uh even today can rewrite

1758

01:10:09,950 --> 01:10:07,500

their their genome and so

1759

01:10:12,590 --> 01:10:09,960

um you know when when did the you know

1760

01:10:14,630 --> 01:10:12,600

of course we we you know we

1761

01:10:17,209 --> 01:10:14,640

the first people didn't

1762

01:10:19,910 --> 01:10:17,219

you know didn't know about that Crick

1763

01:10:21,470 --> 01:10:19,920

called it the central dogma as a joke

1764

01:10:23,750 --> 01:10:21,480

um but today we know that you know

1765

01:10:26,270 --> 01:10:23,760

viruses are doing this or all the time

1766

01:10:29,630 --> 01:10:26,280

so we have lots of endogenous retro bio

1767

01:10:33,709 --> 01:10:29,640

DNA in our own genomes so so I'm not so

1768

01:10:36,169 --> 01:10:33,719

convinced that um that the um the

1769

01:10:38,870 --> 01:10:36,179

central dogma world as it were

1770

01:10:41,930 --> 01:10:38,880

ever existed or at least even exists uh

1771

01:10:44,630 --> 01:10:41,940

even exists exists now but the extent to

1772

01:10:47,750 --> 01:10:44,640

which you know genome editing

1773

01:10:49,250 --> 01:10:47,760

self-genome editing um evolved in time

1774

01:10:50,689 --> 01:10:49,260

that's not something that I've looked at

1775

01:10:52,430 --> 01:10:50,699

but you certainly could you could you

1776

01:10:54,890 --> 01:10:52,440

could imagine it uh suddenly being

1777

01:10:58,490 --> 01:10:54,900

accelerated during the progenya for

1778

01:11:00,410 --> 01:10:58,500

example but it's going on today so so

1779

01:11:02,810 --> 01:11:00,420

um so um

1780

01:11:04,189 --> 01:11:02,820

and did I answer your question or did I

1781

01:11:06,290 --> 01:11:04,199

just dismiss the premise of the question

1782

01:11:08,030 --> 01:11:06,300

and so it swept it under the rug that

1783

01:11:09,830 --> 01:11:08,040

way no it's very fascinating fascinating

1784

01:11:11,930 --> 01:11:09,840

answer I would say biologists would have

1785

01:11:13,370 --> 01:11:11,940

a lot to discussion I would say

1786

01:11:14,870 --> 01:11:13,380

biologists have a lot to discuss with

1787

01:11:16,669 --> 01:11:14,880

you about um the idea of the central

1788

01:11:19,189 --> 01:11:16,679

dogma but I think that is a fascinating

1789

01:11:21,530 --> 01:11:19,199

way to think about it yeah no no I mean

1790

01:11:23,090 --> 01:11:21,540

I mean I mean you know it may be it may

1791

01:11:25,970 --> 01:11:23,100

be broadly true but there's certainly

1792

01:11:27,950 --> 01:11:25,980

lots of exceptions to it and and so uh

1793

01:11:30,530 --> 01:11:27,960

and that's why I say it's not like it

1794

01:11:34,010 --> 01:11:30,540

really has to happen it's it's just you

1795

01:11:36,729 --> 01:11:34,020

know the balance of you know okay mostly

1796

01:11:40,310 --> 01:11:36,739

these things work but the fact um

1797

01:11:42,350 --> 01:11:40,320

they're not forbidden by any symmetry or

1798

01:11:45,950 --> 01:11:42,360

any law laws of physics or anything like

1799

01:11:48,350 --> 01:11:45,960

this so so how you know fundamentally I

1800

01:11:51,350 --> 01:11:48,360

I think the the main principle of trying

1801
01:11:53,810 --> 01:11:51,360
to underlie genome uh genome stability

1802
01:11:55,970 --> 01:11:53,820
is essentially reproducibility in other

1803
01:11:57,649 --> 01:11:55,980
words you know if everything is

1804
01:11:59,390 --> 01:11:57,659
fluctuating too much

1805
01:12:01,189 --> 01:11:59,400
then you're making too many

1806
01:12:02,330 --> 01:12:01,199
possibilities and and then you you're

1807
01:12:04,070 --> 01:12:02,340
getting

1808
01:12:05,810 --> 01:12:04,080
um generalists as well but not new

1809
01:12:08,330 --> 01:12:05,820
Specialists and so it's really tied up

1810
01:12:09,950 --> 01:12:08,340
with you know whether the organisms are

1811
01:12:12,290 --> 01:12:09,960
optimized for their particular

1812
01:12:14,870 --> 01:12:12,300
environment and for the for you know for

1813
01:12:16,130 --> 01:12:14,880

their niches in in the ecosystem so I

1814

01:12:17,450 --> 01:12:16,140

think these these things are balanced

1815

01:12:22,310 --> 01:12:17,460

like that

1816

01:12:26,090 --> 01:12:23,930

so I'm very excited to see you here

1817

01:12:27,950 --> 01:12:26,100

because I'm also physicist by training

1818

01:12:29,450 --> 01:12:27,960

and I have two questions for you so

1819

01:12:31,250 --> 01:12:29,460

first of all can there be nuclear

1820

01:12:33,590 --> 01:12:31,260

signatures for life

1821

01:12:35,270 --> 01:12:33,600

and second question is we just can

1822

01:12:37,310 --> 01:12:35,280

observe five percent of our universe the

1823

01:12:40,970 --> 01:12:37,320

rest of the universe is dark energy dark

1824

01:12:44,149 --> 01:12:40,980

matter can there be dark matter life

1825

01:12:45,770 --> 01:12:44,159

um okay I so the question is are there

1826

01:12:47,630 --> 01:12:45,780

nuclear signatures of life when you say

1827

01:12:49,430 --> 01:12:47,640

nuclear what do you mean by that at the

1828

01:12:51,350 --> 01:12:49,440

nuclear level like we talk about

1829

01:12:57,290 --> 01:12:51,360

biosignatures of Life can there be

1830

01:13:02,209 --> 01:12:59,570

do I don't understand what you mean

1831

01:13:04,130 --> 01:13:02,219

sorry like uh can there be Nuclear

1832

01:13:11,689 --> 01:13:04,140

Physics going on which can lead to life

1833

01:13:17,689 --> 01:13:13,149

I don't know about

1834

01:13:19,850 --> 01:13:17,699

nuclear certainly Atomic I mean there's

1835

01:13:21,590 --> 01:13:19,860

um I don't really I don't know the

1836

01:13:24,649 --> 01:13:21,600

answer to your question but but I'll

1837

01:13:27,410 --> 01:13:24,659

give you an example there's um there is

1838

01:13:28,070 --> 01:13:27,420

a particular excitation

1839

01:13:32,570 --> 01:13:28,080

um

1840

01:13:34,790 --> 01:13:32,580

in carbon the the oil excitation and and

1841

01:13:36,590 --> 01:13:34,800

it's probably the the first or maybe

1842

01:13:39,410 --> 01:13:36,600

only successful application of the

1843

01:13:40,669 --> 01:13:39,420

anthropic principle uh where he guessed

1844

01:13:42,649 --> 01:13:40,679

that there had to be such an excitation

1845

01:13:44,630 --> 01:13:42,659

for some process to occur that was

1846

01:13:46,370 --> 01:13:44,640

essential for life and indeed it was

1847

01:13:47,750 --> 01:13:46,380

later discovered to be true

1848

01:13:49,430 --> 01:13:47,760

so

1849

01:13:51,470 --> 01:13:49,440

I don't really know the answer to your

1850

01:13:54,590 --> 01:13:51,480

question it's not impossible because

1851

01:13:56,270 --> 01:13:54,600

this whole example is is a sort of very

1852

01:13:58,310 --> 01:13:56,280

strange one it's obviously something

1853

01:13:59,209 --> 01:13:58,320

that if you take those sort of

1854

01:14:02,390 --> 01:13:59,219

perspective that you should be looking

1855

01:14:03,830 --> 01:14:02,400

at large scales of systems you would

1856

01:14:05,630 --> 01:14:03,840

never think that there would be this

1857

01:14:07,209 --> 01:14:05,640

kind of thing happening but we also know

1858

01:14:10,010 --> 01:14:07,219

in physics that there was a scale

1859

01:14:11,450 --> 01:14:10,020

interference and that small uh

1860

01:14:13,550 --> 01:14:11,460

negligible effects kind of large

1861

01:14:16,910 --> 01:14:13,560

consequences I have a whole other talk

1862

01:14:19,130 --> 01:14:16,920

about about that in trying to understand

1863

01:14:21,649 --> 01:14:19,140

um the the the tree-like evolution of

1864

01:14:24,950 --> 01:14:21,659

Life which I'm not going to talk about

1865

01:14:26,450 --> 01:14:24,960

um so so I don't I don't really know

1866

01:14:28,250 --> 01:14:26,460

um there was a second question a second

1867

01:14:29,810 --> 01:14:28,260

question was we can only observe five

1868

01:14:32,209 --> 01:14:29,820

percent of our universe because the rest

1869

01:14:33,830 --> 01:14:32,219

of the universe is large right so can

1870

01:14:35,390 --> 01:14:33,840

there be dark matter can there be dark

1871

01:14:43,030 --> 01:14:35,400

matter and can you have can you have

1872

01:14:51,189 --> 01:14:45,590

is very very enthusiastically ready to

1873

01:14:57,169 --> 01:14:55,070

so I I think that the life is you know

1874

01:14:58,729 --> 01:14:57,179

is essentially an inexorable consequence

1875

01:15:00,470 --> 01:14:58,739

of the laws of physics I don't think

1876

01:15:02,930 --> 01:15:00,480

it's Unique or an accident

1877

01:15:05,570 --> 01:15:02,940

so yes that's my answer but I have no

1878

01:15:07,430 --> 01:15:05,580

scientific reason for for answering your

1879

01:15:09,410 --> 01:15:07,440

question in the affirmative

1880

01:15:10,189 --> 01:15:09,420

yes please go ahead yes hello Professor

1881

01:15:14,510 --> 01:15:10,199

like

1882

01:15:16,490 --> 01:15:14,520

am after your talk so thank you thank

1883

01:15:20,510 --> 01:15:16,500

you so much actually I have the similar

1884

01:15:22,550 --> 01:15:20,520

notion like uh I the like uh

1885

01:15:24,350 --> 01:15:22,560

like whatever you have presented here

1886

01:15:25,910 --> 01:15:24,360

like I'm I'm literally feeling we share

1887

01:15:28,490 --> 01:15:25,920

the similar Vibe actually I'm the second

1888

01:15:32,810 --> 01:15:28,500

year PhD student in astronomy and I have

1889

01:15:34,610 --> 01:15:32,820

a degree in physics and so like I'm

1890

01:15:40,010 --> 01:15:34,620

sorry I'm a little nervous but I have I

1891

01:15:47,149 --> 01:15:43,250

so uh yeah I I want to ask like uh What

1892

01:15:49,430 --> 01:15:47,159

uh since uh yeah like I also like

1893

01:15:51,709 --> 01:15:49,440

the earth-centric like investigation of

1894

01:15:53,990 --> 01:15:51,719

life it it it really doesn't convince me

1895

01:15:57,709 --> 01:15:54,000

to for like to to see the life outside

1896

01:15:59,870 --> 01:15:57,719

the universe and so like I'm really

1897

01:16:01,910 --> 01:15:59,880

interested to study the like uh physical

1898

01:16:04,250 --> 01:16:01,920

Evolution like how how we can study the

1899

01:16:07,189 --> 01:16:04,260

life like after the universe like and

1900

01:16:10,370 --> 01:16:07,199

and it is true that uh we should have a

1901

01:16:12,830 --> 01:16:10,380

generic uh like generic definition how

1902

01:16:13,790 --> 01:16:12,840

should life look like so that's why I'm

1903

01:16:15,890 --> 01:16:13,800

very much interested in the

1904

01:16:17,689 --> 01:16:15,900

thermodynamic evolution of life so I

1905

01:16:20,030 --> 01:16:17,699

just want to know like what are your

1906

01:16:21,830 --> 01:16:20,040

thoughts about like what do you what do

1907

01:16:23,930 --> 01:16:21,840

you think about like because there are

1908

01:16:25,490 --> 01:16:23,940

many uh researchers who are doing uh

1909

01:16:27,530 --> 01:16:25,500

great work on that the on the

1910

01:16:29,930 --> 01:16:27,540

thermodynamic evolution of life so I

1911

01:16:32,750 --> 01:16:29,940

just want to know your thoughts on that

1912

01:16:35,750 --> 01:16:32,760

and I'm like I'm super excited to work

1913

01:16:38,270 --> 01:16:35,760

on on this field and uh yeah like even

1914

01:16:40,070 --> 01:16:38,280

uh I'm in second year and I like I have

1915

01:16:41,689 --> 01:16:40,080

already decided I want my second PhD in

1916

01:16:44,030 --> 01:16:41,699

my physics and I want to study the

1917

01:16:45,830 --> 01:16:44,040

thermodynamic evolution of Life So yeah

1918

01:16:50,990 --> 01:16:45,840

thank you

1919

01:16:52,250 --> 01:16:51,000

kind words and um now I don't I don't

1920

01:16:56,750 --> 01:16:52,260

quite understand what is the question

1921

01:17:03,649 --> 01:16:58,850

the microphone is next

1922

01:17:07,130 --> 01:17:03,659

yeah so uh there is uh let the the the

1923

01:17:09,830 --> 01:17:07,140

Third Law of like uh thermodynamics yeah

1924

01:17:11,030 --> 01:17:09,840

the thermo uh yeah the entropy so it it

1925

01:17:13,610 --> 01:17:11,040

says like

1926

01:17:16,669 --> 01:17:13,620

um every natural uh laws in the world

1927

01:17:19,910 --> 01:17:16,679

they have a particular direction and it

1928

01:17:22,550 --> 01:17:19,920

find this is It's that's that's if if we

1929

01:17:25,430 --> 01:17:22,560

think about that that's that's itself is

1930

01:17:28,729 --> 01:17:25,440

a is a very great like itself is a very

1931

01:17:30,110 --> 01:17:28,739

great it tells like every natural you

1932

01:17:32,630 --> 01:17:30,120

know process in the world they have a

1933

01:17:34,610 --> 01:17:32,640

specific Direction and what I feel like

1934

01:17:37,430 --> 01:17:34,620

yeah what I what I feel like that's

1935

01:17:40,130 --> 01:17:37,440

that's my hypothesis like that life is

1936

01:17:42,410 --> 01:17:40,140

not the you know the the most like the

1937

01:17:45,649 --> 01:17:42,420

the most probable state of state of the

1938

01:17:48,110 --> 01:17:45,659

of the nature nature doesn't want right

1939

01:17:50,330 --> 01:17:48,120

that's what I think and I want to study

1940

01:17:52,490 --> 01:17:50,340

this uh with uh like thermodynamic

1941

01:17:54,410 --> 01:17:52,500

evolution of life that's why uh yeah I

1942

01:17:56,510 --> 01:17:54,420

want to study that so I wanted to know

1943

01:17:59,030 --> 01:17:56,520

your uh okay so I think I think I I

1944

01:18:01,070 --> 01:17:59,040

think I'm sorry I was so long

1945

01:18:03,530 --> 01:18:01,080

I think I can paraphrase your your

1946

01:18:05,590 --> 01:18:03,540

question so tell me if this is a

1947

01:18:10,250 --> 01:18:05,600

reasonable paraphrasing of your question

1948

01:18:13,070 --> 01:18:10,260

why why the why does life inexorably

1949

01:18:16,790 --> 01:18:13,080

become more and more complex

1950

01:18:19,130 --> 01:18:16,800

I I and I think that is a very important

1951

01:18:21,050 --> 01:18:19,140

foundational question because you might

1952

01:18:23,870 --> 01:18:21,060

say okay let's suppose you believed in

1953

01:18:26,090 --> 01:18:23,880

the only World which I actually as it

1954

01:18:28,070 --> 01:18:26,100

happens I I don't believe in it but but

1955

01:18:30,530 --> 01:18:28,080

let's suppose you did then you might say

1956

01:18:34,070 --> 01:18:30,540

well okay so I get these uh these uh

1957

01:18:37,130 --> 01:18:34,080

these all the catalytic uh replicators I

1958

01:18:40,250 --> 01:18:37,140

have RNA doing all the functions of of

1959

01:18:42,590 --> 01:18:40,260

Life uh why isn't the world just you

1960

01:18:45,169 --> 01:18:42,600

know knee-deep in uh self-replicating

1961

01:18:47,390 --> 01:18:45,179

RNA molecules you know why do we have

1962

01:18:49,729 --> 01:18:47,400

arts and elephants and and blue whales

1963

01:18:51,250 --> 01:18:49,739

and things like this and so so I think

1964

01:18:54,830 --> 01:18:51,260

the the you know the the

1965

01:18:57,590 --> 01:18:54,840

fundamental question is why do you have

1966

01:19:00,530 --> 01:18:57,600

this uh Evolution to greater and greater

1967

01:19:01,790 --> 01:19:00,540

complexity and I think that's a

1968

01:19:04,130 --> 01:19:01,800

um that's a question that we don't have

1969

01:19:05,570 --> 01:19:04,140

a good answer for now I'll tell you what

1970

01:19:07,250 --> 01:19:05,580

happens when we try to model living

1971

01:19:12,169 --> 01:19:07,260

systems

1972

01:19:14,270 --> 01:19:12,179

say in a computer you make an artificial

1973

01:19:17,030 --> 01:19:14,280

ecosystem lots of things interacting

1974

01:19:19,189 --> 01:19:17,040

with each other and you run it and what

1975

01:19:21,350 --> 01:19:19,199

happens is it does evolve in complexity

1976

01:19:22,370 --> 01:19:21,360

just a little bit and then it just stops

1977

01:19:24,590 --> 01:19:22,380

evolving

1978

01:19:26,930 --> 01:19:24,600

it just stay it stays constantly and it

1979

01:19:29,330 --> 01:19:26,940

really the simulation does not involve

1980

01:19:33,530 --> 01:19:29,340

more and more arbitrarily complex Life

1981

01:19:36,830 --> 01:19:33,540

As Time proceeds so we try to figure out

1982

01:19:39,229 --> 01:19:36,840

uh what is the fundamental mechanisms

1983

01:19:41,930 --> 01:19:39,239

genetic mechanisms that could enable

1984

01:19:45,890 --> 01:19:41,940

this increase to give you as you put it

1985

01:19:48,110 --> 01:19:45,900

this directionality of life and what we

1986

01:19:50,570 --> 01:19:48,120

discovered was this and it relates to

1987

01:19:53,149 --> 01:19:50,580

things I emphasize in the talk

1988

01:19:54,470 --> 01:19:53,159

mostly when we think about Evolution you

1989

01:19:57,050 --> 01:19:54,480

know you read the newspapers you think

1990

01:19:59,270 --> 01:19:57,060

about uh mutations and point mutations

1991

01:20:01,550 --> 01:19:59,280

and things like this I don't think those

1992

01:20:03,290 --> 01:20:01,560

things are very important at all for

1993

01:20:06,169 --> 01:20:03,300

evolution on the large scale what we

1994

01:20:08,689 --> 01:20:06,179

discovered in computer simulations was

1995

01:20:11,209 --> 01:20:08,699

that there's two things that cause life

1996

01:20:13,189 --> 01:20:11,219

to inexorably get more and more complex

1997

01:20:16,090 --> 01:20:13,199

and that is first of all you have

1998

01:20:18,830 --> 01:20:16,100

horizontal Gene transfer so you have

1999

01:20:19,669 --> 01:20:18,840

mechanisms that enable

2000

01:20:22,130 --> 01:20:19,679

um

2001

01:20:24,470 --> 01:20:22,140

essentially an evolving system to really

2002

01:20:27,110 --> 01:20:24,480

find its its local maximum or local

2003

01:20:28,430 --> 01:20:27,120

minimum Optimum and the other is Gene

2004

01:20:32,630 --> 01:20:28,440

duplication

2005

01:20:34,430 --> 01:20:32,640

because you make a copy of a gene and

2006

01:20:35,810 --> 01:20:34,440

then one copy goes off and Carries On

2007

01:20:37,689 --> 01:20:35,820

doing what it was supposed to be doing

2008

01:20:40,610 --> 01:20:37,699

the other one can evolve without

2009

01:20:42,050 --> 01:20:40,620

deleterious effect on the organism and

2010

01:20:44,830 --> 01:20:42,060

when you look in in The evolutionary

2011

01:20:47,510 --> 01:20:44,840

history of of life and you look at uh

2012

01:20:49,310 --> 01:20:47,520

genomes you see throughout this

2013

01:20:52,189 --> 01:20:49,320

pervasive influence of horizontal Gene

2014

01:20:55,550 --> 01:20:52,199

transversely in microbial organisms and

2015

01:20:58,550 --> 01:20:55,560

um and and and Gene duplication and you

2016

01:20:59,689 --> 01:20:58,560

see Gene duplication in all branches of

2017

01:21:02,030 --> 01:20:59,699

life

2018

01:21:04,790 --> 01:21:02,040

um so so I think what you have to try to

2019

01:21:05,990 --> 01:21:04,800

understand is the the interplay between

2020

01:21:09,110 --> 01:21:06,000

these different

2021

01:21:11,030 --> 01:21:09,120

our processes at the genetic level then

2022

01:21:14,450 --> 01:21:11,040

have consequences for the large-scale

2023

01:21:18,350 --> 01:21:14,460

complexity of organisms so we we built

2024

01:21:22,610 --> 01:21:19,850

um computer model of an evolving

2025

01:21:25,510 --> 01:21:22,620

ecosystem which has continual growth of

2026

01:21:28,610 --> 01:21:25,520

complexity due to those particular

2027

01:21:30,590 --> 01:21:28,620

genetic operators and it's not a very

2028

01:21:32,810 --> 01:21:30,600

realistic model and the model and the

2029

01:21:35,330 --> 01:21:32,820

method of the the way we measured

2030

01:21:37,250 --> 01:21:35,340

complexity was completely unrealistic

2031

01:21:39,410 --> 01:21:37,260

and we measured it by the length of the

2032

01:21:41,209 --> 01:21:39,420

genome as opposed to something like

2033

01:21:44,030 --> 01:21:41,219

common golf complexity or some other

2034

01:21:47,770 --> 01:21:44,040

algorithmic complexity measure but um

2035

01:21:51,649 --> 01:21:47,780

but it it does show you that certain

2036

01:21:52,910 --> 01:21:51,659

genetic processes can give rise when

2037

01:21:54,530 --> 01:21:52,920

they interact with the environment and

2038

01:21:57,410 --> 01:21:54,540

that was important in our in our

2039

01:21:59,750 --> 01:21:57,420
calculation I can give rise to this

2040

01:22:01,370 --> 01:21:59,760
direction of life this ever increasing

2041

01:22:02,990 --> 01:22:01,380
growth of complexity

2042

01:22:05,810 --> 01:22:03,000
so that's the best I can do in answering

2043

01:22:07,370 --> 01:22:05,820
your question is that helpful

2044

01:22:08,930 --> 01:22:07,380
okay unfortunately run out of time for

2045

01:22:10,550 --> 01:22:08,940
questions hopefully you can find Nigel

2046

01:22:15,380 --> 01:22:10,560
at the dinner but let's thank our