Complexity:
History of Prokaryote vs. Protist

Chatton, **1925**

Large genomes/more proteins

Cooper, NCBI, **2000**

Information Content

Böttcher, J Mol. Evol., **2018** & Koonin, Phil. Trans. Roy. Soc., **2016**

Organelles

Berkley, Understanding Evolution, & Fuerst, Scitable **2010**

1
00:00:06,230 --> 00:00:04,230
hello my name is teddy harriman i'm a

2
00:00:08,390 --> 00:00:06,240
first year grad student in the chemistry

3
00:00:09,990 --> 00:00:08,400
and biochemistry department at montana

4
00:00:11,830 --> 00:00:10,000
state university

5
00:00:14,390 --> 00:00:11,840
today i will be discussing the

6
00:00:17,349 --> 00:00:14,400
comparative complexity of cells in

7
00:00:18,950 --> 00:00:17,359
particular the complexity of microbes

8
00:00:22,470 --> 00:00:18,960
so that is the difference between

9
00:00:24,790 --> 00:00:22,480
prokaryotes archaea and bacteria versus

10
00:00:27,029 --> 00:00:24,800
eukaryotes but more specifically in this

11
00:00:29,750 --> 00:00:27,039
case protists the single celled version

12
00:00:34,470 --> 00:00:31,990
now i would argue that the goals of

13
00:00:37,270 --> 00:00:34,480

measuring complexity or comparing it

14
00:00:38,950 --> 00:00:37,280
between cells are at least two faceted

15
00:00:40,869 --> 00:00:38,960
the first component would be to

16
00:00:42,549 --> 00:00:40,879
constrain phylogenys

17
00:00:45,430 --> 00:00:42,559
at the moment there are three to four

18
00:00:47,350 --> 00:00:45,440
phylogenys that are cited the difference

19
00:00:49,910 --> 00:00:47,360
between these phylogenys are not just

20
00:00:52,950 --> 00:00:49,920
their results but the methodologies that

21
00:00:55,750 --> 00:00:52,960
they use for instance many use amino

22
00:00:57,189 --> 00:00:55,760
acid sequence comparisons some compare

23
00:00:59,990 --> 00:00:57,199
protein folds

24
00:01:01,910 --> 00:01:00,000
other compare information content so on

25
00:01:04,310 --> 00:01:01,920
and so forth the issue that they all

26
00:01:06,310 --> 00:01:04,320
seem to have is how to appropriately

27
00:01:09,590 --> 00:01:06,320
quote unquote root the tree

28
00:01:12,630 --> 00:01:09,600
which is to say which uh where do cells

29
00:01:15,350 --> 00:01:12,640
line up in terms of being in relation to

30
00:01:17,590 --> 00:01:15,360
a last universal cellular ancestor and

31
00:01:19,830 --> 00:01:17,600
how are they specifically related to

32
00:01:22,070 --> 00:01:19,840
each other evolutionarily

33
00:01:25,109 --> 00:01:22,080
on top of this there's an issue of

34
00:01:27,990 --> 00:01:25,119
adding viruses into the domains and

35
00:01:30,230 --> 00:01:28,000
figuring out where they fit

36
00:01:32,390 --> 00:01:30,240
within the tree of life the big issue

37
00:01:33,910 --> 00:01:32,400
here of course is viral genomes are so

38
00:01:36,630 --> 00:01:33,920

small that even if you're comparing

39
00:01:38,310 --> 00:01:36,640
amino acids or protein folds there's not

40
00:01:41,109 --> 00:01:38,320
a great way to compare them to the much

41
00:01:43,030 --> 00:01:41,119
larger genomes of cells

42
00:01:44,789 --> 00:01:43,040
now the second one which is especially

43
00:01:47,270 --> 00:01:44,799
important for origins of life is to

44
00:01:50,550 --> 00:01:47,280
constrain identity and properties of the

45
00:01:53,030 --> 00:01:50,560
progenites versus the last

46
00:01:55,350 --> 00:01:53,040
universal cellular ancestor

47
00:01:58,469 --> 00:01:55,360
which is to say can we say something

48
00:02:01,270 --> 00:01:58,479
about the simplicity and or complexity

49
00:02:03,910 --> 00:02:01,280
of luca and identify which biological

50
00:02:06,709 --> 00:02:03,920
features are quote unquote simple and or

51
00:02:09,589 --> 00:02:06,719
complex and therefore should be expected

52
00:02:11,910 --> 00:02:09,599
as the first form of life

53
00:02:14,070 --> 00:02:11,920
with this in mind i want to discuss some

54
00:02:16,710 --> 00:02:14,080
assumptions of biological complexity

55
00:02:19,190 --> 00:02:16,720
that are either implicitly or explicitly

56
00:02:21,510 --> 00:02:19,200
stated within the literature

57
00:02:23,910 --> 00:02:21,520
the first and foremost which is very key

58
00:02:26,229 --> 00:02:23,920
to origins of life in astrobiology is

59
00:02:28,630 --> 00:02:26,239
the idea that complexity increases over

60
00:02:30,550 --> 00:02:28,640
time which is to say we assume that the

61
00:02:32,949 --> 00:02:30,560
ancestral biosphere

62
00:02:35,750 --> 00:02:32,959
is less complex in a measurable way than

63
00:02:38,150 --> 00:02:35,760

the present biosphere and that ancestral

64
00:02:40,150 --> 00:02:38,160
organisms are also less complex than

65
00:02:42,150 --> 00:02:40,160
present day organisms

66
00:02:44,390 --> 00:02:42,160
with some numeric value of complexity

67
00:02:46,150 --> 00:02:44,400
assigned

68
00:02:49,030 --> 00:02:46,160
the second component is that life is

69
00:02:51,030 --> 00:02:49,040
complex so we assume traditionally that

70
00:02:53,350 --> 00:02:51,040
non-life is less complex than life and

71
00:02:58,390 --> 00:02:53,360
that this is a key identifier of what is

72
00:03:02,949 --> 00:03:00,630
as i alluded to it's important to have

73
00:03:05,509 --> 00:03:02,959
an exact mathematical definition for

74
00:03:07,110 --> 00:03:05,519
what you mean when you say complex

75
00:03:09,110 --> 00:03:07,120
in this case i'm going to be using what

76
00:03:11,270 --> 00:03:09,120
i call temporal information density or

77
00:03:12,630 --> 00:03:11,280
tid which is the amount of shannon

78
00:03:14,630 --> 00:03:12,640
information

79
00:03:16,869 --> 00:03:14,640
it takes to describe an object whether

80
00:03:19,430 --> 00:03:16,879
that's a biological object like a cell

81
00:03:22,070 --> 00:03:19,440
or other inanimate object divided by

82
00:03:23,509 --> 00:03:22,080
that object's overall mass

83
00:03:26,390 --> 00:03:23,519
times the amount of time you are

84
00:03:28,309 --> 00:03:26,400
actually looking at that object

85
00:03:30,830 --> 00:03:28,319
now the units for that would be number

86
00:03:32,550 --> 00:03:30,840
of bits per gram

87
00:03:34,630 --> 00:03:32,560
second

88
00:03:35,990 --> 00:03:34,640

for simplicity's sake bits you can think

89
00:03:38,630 --> 00:03:36,000
of how much

90
00:03:39,830 --> 00:03:38,640
uh space it would take to describe that

91
00:03:41,910 --> 00:03:39,840
object

92
00:03:43,670 --> 00:03:41,920
on a hard drive divided by its actual

93
00:03:46,390 --> 00:03:43,680
physical size

94
00:03:47,670 --> 00:03:46,400
so implicit in this

95
00:03:50,470 --> 00:03:47,680
derivation

96
00:03:52,550 --> 00:03:50,480
is the idea that size is just size and

97
00:03:55,190 --> 00:03:52,560
something can be big and simply big and

98
00:03:57,509 --> 00:03:55,200
not necessarily complex so for instance

99
00:03:59,589 --> 00:03:57,519
if i were comparing computers

100
00:04:00,949 --> 00:03:59,599
i would be first curious to know how

101
00:04:03,110 --> 00:04:00,959
much information it would take to

102
00:04:05,030 --> 00:04:03,120
describe that computer and then i would

103
00:04:07,350 --> 00:04:05,040
want to divide it by the computer's

104
00:04:09,830 --> 00:04:07,360
overall size which is to say the

105
00:04:12,710 --> 00:04:09,840
smallest computer that can

106
00:04:14,390 --> 00:04:12,720
produces the same functionality

107
00:04:15,830 --> 00:04:14,400
with the same amount of information to

108
00:04:19,990 --> 00:04:15,840
describe it

109
00:04:24,710 --> 00:04:22,069
now to understand the difference between

110
00:04:26,150 --> 00:04:24,720
prokaryote and protist complexity it is

111
00:04:29,110 --> 00:04:26,160
important to understand the history and

112
00:04:30,870 --> 00:04:29,120
the context of where claims come from i

113
00:04:33,270 --> 00:04:30,880

would argue the first

114
00:04:35,749 --> 00:04:33,280
statement of prokaryotes being simpler

115
00:04:38,230 --> 00:04:35,759
than protists began with edward chattan

116
00:04:41,189 --> 00:04:38,240
in 1925 when he first coined the terms

117
00:04:42,469 --> 00:04:41,199
prokaryote and eukaryote in those terms

118
00:04:44,469 --> 00:04:42,479
prokaryote

119
00:04:47,430 --> 00:04:44,479
is greek for essentially before the

120
00:04:49,189 --> 00:04:47,440
nucleus and protis means true nucleus

121
00:04:50,550 --> 00:04:49,199
and that he established one became

122
00:04:52,629 --> 00:04:50,560
before the other

123
00:04:55,430 --> 00:04:52,639
and also implicitly and to a certain

124
00:04:57,510 --> 00:04:55,440
degree explicitly implied that this was

125
00:05:00,230 --> 00:04:57,520
because prokaryotes were simpler which

126
00:05:02,710 --> 00:05:00,240
based on his microscopy made a lot of

127
00:05:06,710 --> 00:05:05,029
since that time

128
00:05:10,070 --> 00:05:06,720
a number of other measurements have been

129
00:05:12,710 --> 00:05:10,080
used to claim protus higher complexity

130
00:05:13,909 --> 00:05:12,720
among them are larger genomes slash more

131
00:05:16,310 --> 00:05:13,919
proteins

132
00:05:18,390 --> 00:05:16,320
the issue of course is known today that

133
00:05:21,270 --> 00:05:18,400
if we were to assume that this is the

134
00:05:23,430 --> 00:05:21,280
case you'll have many logical fallacies

135
00:05:27,270 --> 00:05:23,440
such as human beings would be less

136
00:05:31,189 --> 00:05:29,110
somewhat more recently information

137
00:05:32,870 --> 00:05:31,199
content has been used to claim

138
00:05:34,950 --> 00:05:32,880

complexity

139
00:05:37,590 --> 00:05:34,960
in at least two examples with sample

140
00:05:39,510 --> 00:05:37,600
sizes under

141
00:05:41,590 --> 00:05:39,520
two authors have claimed that total

142
00:05:44,550 --> 00:05:41,600
information content can be used to

143
00:05:46,950 --> 00:05:44,560
measure something's complexity however i

144
00:05:49,110 --> 00:05:46,960
will mention that even kunin in his

145
00:05:51,270 --> 00:05:49,120
paper along these lines mentioned that

146
00:05:53,909 --> 00:05:51,280
prokaryotes appeared admittedly better

147
00:05:57,110 --> 00:05:55,189
the third

148
00:05:59,350 --> 00:05:57,120
way that people claim complexity that

149
00:06:01,990 --> 00:05:59,360
i've at least found is that it's because

150
00:06:03,670 --> 00:06:02,000
eukaryotes have organelles whereas

151
00:06:05,430 --> 00:06:03,680
prokaryotes do not

152
00:06:07,830 --> 00:06:05,440
this today we know not to be true

153
00:06:09,749 --> 00:06:07,840
prokaryotes do in fact have organelles

154
00:06:11,830 --> 00:06:09,759
it seems the large difference between

155
00:06:14,150 --> 00:06:11,840
the types of organelles they have is

156
00:06:16,550 --> 00:06:14,160
that protein uh prokaryotes tend to have

157
00:06:18,309 --> 00:06:16,560
protein-based organization whereas

158
00:06:21,510 --> 00:06:18,319
eukaryotes depend heavily on their

159
00:06:23,350 --> 00:06:21,520
lipid-based organization

160
00:06:25,670 --> 00:06:23,360
and finally and

161
00:06:28,629 --> 00:06:25,680
is the idea that you can associate

162
00:06:30,870 --> 00:06:28,639
eukaryotic multi-cellularity to protist

163
00:06:33,510 --> 00:06:30,880

complexity in the sense that protists

164
00:06:35,510 --> 00:06:33,520
could have the potential to evolve into

165
00:06:39,270 --> 00:06:35,520
multicellular organisms whereas

166
00:06:41,110 --> 00:06:39,280
prokaryotes can only superficially do so

167
00:06:43,189 --> 00:06:41,120
this last point should be addressed

168
00:06:45,350 --> 00:06:43,199
further and can be addressed from a

169
00:06:47,430 --> 00:06:45,360
simple thought experiment which is could

170
00:06:50,469 --> 00:06:47,440
multicellularity evolve in the absence

171
00:06:52,629 --> 00:06:50,479
of prokaryotes the answer is no

172
00:06:55,749 --> 00:06:52,639
at least from an ecosystem in biospheric

173
00:06:57,830 --> 00:06:55,759
perspective multicellular eukaryotes are

174
00:07:00,150 --> 00:06:57,840
two component machines

175
00:07:02,150 --> 00:07:00,160
this has been addressed by the idea that

176
00:07:04,830 --> 00:07:02,160
if we were to eliminate all the

177
00:07:08,629 --> 00:07:04,840
prokaryotes on earth today

178
00:07:10,070 --> 00:07:08,639
biogeochemical cycles nitrogen fixation

179
00:07:11,909 --> 00:07:10,080
uh and

180
00:07:15,110 --> 00:07:11,919
many of the phages that we have that

181
00:07:16,070 --> 00:07:15,120
regulate our ecosystems would disappear

182
00:07:18,150 --> 00:07:16,080
and

183
00:07:21,029 --> 00:07:18,160
in particular with the loss of nitrogen

184
00:07:23,189 --> 00:07:21,039
fixation you could expect photosynthesis

185
00:07:25,110 --> 00:07:23,199
to die out within a year

186
00:07:27,110 --> 00:07:25,120
on top of this there's an even older

187
00:07:28,870 --> 00:07:27,120
idea which is the energy pyramid

188
00:07:30,909 --> 00:07:28,880

sometimes known as the trophic energy

189
00:07:33,110 --> 00:07:30,919
pyramid which is to say that

190
00:07:34,629 --> 00:07:33,120
multicellularity is regulated from the

191
00:07:36,390 --> 00:07:34,639
bottom up

192
00:07:38,309 --> 00:07:36,400
if we were to take prokaryotes out of

193
00:07:40,469 --> 00:07:38,319
the picture and be left entirely with

194
00:07:42,550 --> 00:07:40,479
protists as well addressed a bit more on

195
00:07:45,350 --> 00:07:42,560
the next slide there would not be enough

196
00:07:49,270 --> 00:07:45,360
energy for multicellularity to both

197
00:07:53,909 --> 00:07:51,510
now there are in fact some reasons to

198
00:07:56,710 --> 00:07:53,919
assume that the dogma of

199
00:07:59,830 --> 00:07:56,720
prokaryotes simplicity in comparison to

200
00:08:01,990 --> 00:07:59,840
protists might actually be incorrect

201
00:08:03,909 --> 00:08:02,000
first and foremost is that protist

202
00:08:06,309 --> 00:08:03,919
adaptability is not as good as

203
00:08:07,830 --> 00:08:06,319
prokaryotes ability to adapt

204
00:08:10,469 --> 00:08:07,840
how this could be measured is by the

205
00:08:12,390 --> 00:08:10,479
number of niches that protists occupy in

206
00:08:14,550 --> 00:08:12,400
comparison to prokaryotes

207
00:08:16,390 --> 00:08:14,560
what do i mean by niche i mean the

208
00:08:18,150 --> 00:08:16,400
number of environments they inhabit and

209
00:08:19,749 --> 00:08:18,160
also the metabolisms that they are

210
00:08:22,629 --> 00:08:19,759
actually capable of

211
00:08:24,790 --> 00:08:22,639
so for instance prokaryotes are abundant

212
00:08:26,790 --> 00:08:24,800
within deep sea hydrothermal vents

213
00:08:28,710 --> 00:08:26,800

whereas at least single-celled

214
00:08:30,390 --> 00:08:28,720
eukaryotes are unable to live in that

215
00:08:32,870 --> 00:08:30,400
such environments

216
00:08:35,589 --> 00:08:32,880
in addition while protists only have

217
00:08:37,909 --> 00:08:35,599
access to respiration and photosynthesis

218
00:08:39,909 --> 00:08:37,919
as far as we know prokaryotes have many

219
00:08:41,670 --> 00:08:39,919
other forms of metabolisms that allow

220
00:08:42,790 --> 00:08:41,680
them to access other environmental

221
00:08:45,670 --> 00:08:42,800
niches

222
00:08:47,829 --> 00:08:45,680
as a side comparison to this as well it

223
00:08:49,750 --> 00:08:47,839
is pretty uh well accepted that

224
00:08:51,829 --> 00:08:49,760
prokaryotes are more adaptable in the

225
00:08:54,070 --> 00:08:51,839
sense that we can also throw them into

226
00:08:56,150 --> 00:08:54,080
say the vacuum of space and they will be

227
00:08:58,150 --> 00:08:56,160
able to adapt at least to a certain

228
00:08:59,829 --> 00:08:58,160
extent

229
00:09:02,550 --> 00:08:59,839
the second point is that protis

230
00:09:04,310 --> 00:09:02,560
metabolic speed is less than prokaryotic

231
00:09:06,070 --> 00:09:04,320
metabolic speed

232
00:09:08,710 --> 00:09:06,080
and this is true for both respiration

233
00:09:10,870 --> 00:09:08,720
and photosynthesis by mass

234
00:09:13,350 --> 00:09:10,880
now if you are to accept that

235
00:09:15,190 --> 00:09:13,360
dissipation of energy as many do within

236
00:09:16,949 --> 00:09:15,200
the astrobiological community is

237
00:09:19,350 --> 00:09:16,959
fundamental to life

238
00:09:22,070 --> 00:09:19,360

then it would seem odd that the species

239
00:09:23,750 --> 00:09:22,080
that is slower at dissipating energy

240
00:09:24,870 --> 00:09:23,760
would be determined as being more

241
00:09:26,470 --> 00:09:24,880
complex

242
00:09:29,430 --> 00:09:26,480
in total with both of these we could

243
00:09:31,430 --> 00:09:29,440
almost assume that adaptability and

244
00:09:34,389 --> 00:09:31,440
dissipation of energy are not actually

245
00:09:36,310 --> 00:09:34,399
very much fundamental to biology and or

246
00:09:39,430 --> 00:09:36,320
they're not fundamental biological

247
00:09:42,710 --> 00:09:39,440
indicators of evolution

248
00:09:44,630 --> 00:09:42,720
last but not least that uh protist bio

249
00:09:47,269 --> 00:09:44,640
chemical tid is potentially lower than

250
00:09:48,870 --> 00:09:47,279
prokaryotic biochemical tid tid of

251
00:09:51,670 --> 00:09:48,880
course being the measurement of

252
00:09:53,750 --> 00:09:51,680
complexity i presented earlier

253
00:09:55,910 --> 00:09:53,760
i can gauge this by the lower proportion

254
00:09:57,350 --> 00:09:55,920
of lipids and lipid organization within

255
00:09:59,990 --> 00:09:57,360
prokaryotes

256
00:10:02,310 --> 00:10:00,000
lipids by even bochner were entirely

257
00:10:03,750 --> 00:10:02,320
left out of his mathematical formulation

258
00:10:05,590 --> 00:10:03,760
because they were considered to

259
00:10:09,750 --> 00:10:05,600
entropically

260
00:10:15,190 --> 00:10:12,710
in conclusion complexity deserves to not

261
00:10:16,790 --> 00:10:15,200
just be an abstraction but a numerical

262
00:10:18,550 --> 00:10:16,800
value that we can use to compare

263
00:10:20,550 --> 00:10:18,560

biological entities as well as

264
00:10:22,949 --> 00:10:20,560
non-biological entities

265
00:10:25,110 --> 00:10:22,959
and so doing so we might be able to have

266
00:10:26,870 --> 00:10:25,120
a better understanding of how life

267
00:10:28,550 --> 00:10:26,880
evolves and potentially what life

268
00:10:30,069 --> 00:10:28,560
evolved from

269
00:10:32,389 --> 00:10:30,079
as it stands there's a darth of

270
00:10:34,630 --> 00:10:32,399
literature in regards to biological

271
00:10:38,470 --> 00:10:34,640
complexity there's even less literature

272
00:10:40,389 --> 00:10:38,480
that actively compares living organisms

273
00:10:42,069 --> 00:10:40,399
at the moment there also appears to be

274
00:10:45,110 --> 00:10:42,079
some indicators of fundamental

275
00:10:48,550 --> 00:10:45,120
biological ideas that indicate that it

276
00:10:50,790 --> 00:10:48,560
is possible that prokaryotes are in fact

277
00:10:52,550 --> 00:10:50,800
just as complex if not more complex than

278
00:10:54,470 --> 00:10:52,560
protists

279
00:10:57,509 --> 00:10:54,480
i thank you for your time if you have

280
00:10:59,269 --> 00:10:57,519
any information regarding complexity

281
00:11:01,750 --> 00:10:59,279
context i might have missed and or would

282
00:11:03,990 --> 00:11:01,760
like to discuss prokaryotic complexity