



1
00:00:01,000 --> 00:00:08,800
[music playing]

2
00:00:16,300 --> 00:00:19,166
- IT--IT'S MY VERY,
VERY GREAT HONOR TODAY

3
00:00:19,166 --> 00:00:23,466
TO--TO INTRODUCE
THIS DIRECTOR'S COLLOQUIUM.

4
00:00:23,466 --> 00:00:26,033
YOU KNOW,

5
00:00:26,033 --> 00:00:30,766
IT'S BEEN KIND OF
AN INTERESTING FEW YEARS.

6
00:00:30,766 --> 00:00:33,333
YOU KNOW,
AND DEEP SPACE EXPLORATION

7
00:00:33,333 --> 00:00:35,933
AND SETTLEMENT--
I'LL USE THAT WORD--

8
00:00:35,933 --> 00:00:39,400
IS GONNA REQUIRE
AN IN-DEPTH UNDERSTANDING

9
00:00:39,400 --> 00:00:41,933
OF LIFE AND LIFE PROCESSES.

10
00:00:41,933 --> 00:00:45,133
AND, YOU KNOW,
I'VE BECOME FIRMLY CONVINCED--

11
00:00:45,133 --> 00:00:47,733
WHICH IS AN AMAZING THING,

'CAUSE I'M AN ASTROPHYSICIST--

12

00:00:47,733 --> 00:00:50,866
THAT BIOLOGY IS PROBABLY
THE MOST IMPORTANT TECHNOLOGY

13

00:00:50,866 --> 00:00:54,033
FOR THIS CENTURY.

14

00:00:54,033 --> 00:00:57,033
[applause]

15

00:00:58,533 --> 00:01:01,266
IN FACT, ASTROPHYSICS
IS ABOUT LOOKING FOR LIFE,

16

00:01:01,266 --> 00:01:03,000
SO WE'RE BIOLOGISTS, TOO.

17

00:01:03,000 --> 00:01:04,766
AND, YOU KNOW, OF COURSE,
AMES IS THE--

18

00:01:04,766 --> 00:01:07,266
IS THE LEAD CENTER FOR
FUNDAMENTAL SPACE BIOLOGY

19

00:01:07,266 --> 00:01:09,933
AND FOR SYNTHETIC BIOLOGY
FOR THE AGENCY.

20

00:01:09,933 --> 00:01:13,466
AND TODAY, WE HAVE THE--

21

00:01:13,466 --> 00:01:15,600
YOU KNOW,
ONE OF THE NEATEST GUYS

22

00:01:15,600 --> 00:01:17,200

I HAVE EVER MET,

23

00:01:17,200 --> 00:01:19,333
AND HE'S THE LEAD SCIENTIST
IN GENETIC--

24

00:01:19,333 --> 00:01:21,100
IN GENOMIC--PARDON ME--
GENOMIC RESEARCH

25

00:01:21,100 --> 00:01:23,366
FOR THE 21ST CENTURY--
J. CRAIG VENTER.

26

00:01:23,366 --> 00:01:26,533
AND HE'S GONNA SPEAK
ABOUT THE PROFOUND IMPACTS

27

00:01:26,533 --> 00:01:28,733
THESE TOOLS WILL HAVE
ON HUMANS' EXISTENCE

28

00:01:28,733 --> 00:01:30,633
ON EARTH AND BEYOND.

29

00:01:30,633 --> 00:01:32,366
HE WAS LISTED

30

00:01:32,366 --> 00:01:36,000
ON "TIME" MAGAZINE'S
2007 AND 2008 100 LIST

31

00:01:36,000 --> 00:01:38,133
OF THE MOST INFLUENTIAL PEOPLE
IN THE WORLD.

32

00:01:38,133 --> 00:01:41,400
IN 2010, THE BRITISH MAGAZINE
"NEW STATESMAN"

33

00:01:41,400 --> 00:01:44,333

LISTED HIM AS 14TH
IN A LIST OF THE 50--

34

00:01:44,333 --> 00:01:47,733

WORLD'S 50 MOST
INFLUENTIAL FIGURES.

35

00:01:47,733 --> 00:01:51,500

HE BEGAN HIS FORMAL EDUCATION
AFTER TOURS IN NAVY CORP--

36

00:01:51,500 --> 00:01:55,833

CORPSMAN IN VIETNAM
FROM 1967/1968.

37

00:01:55,833 --> 00:01:57,900

AND AFTER EARNING BOTH
A BACHELOR'S DEGREE

38

00:01:57,900 --> 00:01:59,366

IN BIOCHEMISTRY

39

00:01:59,366 --> 00:02:03,000

AND A PhD IN--IN PHYSIOLOGY
AND PHARMACOLOGY

40

00:02:03,000 --> 00:02:04,966

FROM THE UNIVERSITY
OF CALIFORNIA AT SAN DIEGO--

41

00:02:04,966 --> 00:02:07,966

A LOCAL BOY, SORT OF--

42

00:02:07,966 --> 00:02:10,333

HE WAS PERFORMED--
APPOINTED PROFESSOR

43

00:02:10,333 --> 00:02:12,566

AT THE STATE UNIVERSITY
OF NEW YORK AT BUFFALO

44

00:02:12,566 --> 00:02:16,433
IN THE ROSWELL PARK
CANCER INSTITUTE.

45

00:02:16,433 --> 00:02:18,333
TODAY'S TALK BY HIM

46

00:02:18,333 --> 00:02:20,566
IS ENTITLED
"LIFE AT THE SPEED OF LIGHT."

47

00:02:20,566 --> 00:02:23,166
PLEASE HELP ME WELCOME

48

00:02:23,166 --> 00:02:26,800
DR. CRAIG VENTER,
WHO IS A COOL GUY AND A FRIEND,

49

00:02:26,800 --> 00:02:28,900
AND HE'S GONNA TELL YOU
SOME REALLY COOL STUFF.

50

00:02:28,900 --> 00:02:31,333
CRAIG.

51

00:02:31,333 --> 00:02:33,300
[applause]

52

00:02:33,300 --> 00:02:36,300
[indistinct conversation]

53

00:02:42,400 --> 00:02:44,900
- THAT'S ONE OF THE BIGGEST
CHALLENGES I'VE HAD NOW--

54

00:02:44,900 --> 00:02:46,966

I HAVE TO SAY
SOMETHING COOL.

55
00:02:46,966 --> 00:02:48,733
[laughter]

56
00:02:48,733 --> 00:02:52,433
SO THAT'S A--THAT'S A CHALLENGE
AT NASA AMES,

57
00:02:52,433 --> 00:02:54,700
WHERE SO MUCH OF THE STUFF HERE
IS COOL.

58
00:02:54,700 --> 00:02:58,833
SO I'M EXCITED
TO BE BACK HERE AGAIN.

59
00:02:58,833 --> 00:03:02,700
AND, PETE, THANK YOU--
THANK YOU FOR INVITING ME,

60
00:03:02,700 --> 00:03:05,066
ONCE AGAIN, TO JOIN YOU.

61
00:03:05,066 --> 00:03:08,000
SO SEEING THAT MY BROTHER
HAS SOMETHING TO DO

62
00:03:08,000 --> 00:03:09,666
WITH BUILDINGS HERE,

63
00:03:09,666 --> 00:03:11,466
I THOUGHT
I'D SHOW A NICER BUILDING

64
00:03:11,466 --> 00:03:13,066
THAN YOU GUYS HAVE HERE.

65

00:03:13,066 --> 00:03:15,200
[laughter]

66
00:03:15,200 --> 00:03:16,966
SORRY, KEITH.

67
00:03:16,966 --> 00:03:19,766
THIS IS
THE VENTER INSTITUTE BUILDING

68
00:03:19,766 --> 00:03:22,066
IN LA JOLLA, CALIFORNIA.

69
00:03:22,066 --> 00:03:24,433
IT'S ON THE UCSD CAMPUS,

70
00:03:24,433 --> 00:03:26,300
AND IT'S THE FIRST

71
00:03:26,300 --> 00:03:29,300
TRUE CARBON-NEUTRAL
RESEARCH BUILDING.

72
00:03:29,300 --> 00:03:31,633
AND I HEAR EVEN NASA

73
00:03:31,633 --> 00:03:33,633
CAN MAKE CARBON-NEUTRAL
OFFICE BUILDINGS,

74
00:03:33,633 --> 00:03:36,433
BUT GETTING A CARBON-NEUTRAL
RESEARCH BUILDING

75
00:03:36,433 --> 00:03:39,833
WITH WET LABS
AND MACHINERY

76
00:03:39,833 --> 00:03:42,066

AND FUME HOODS AND STUFF
WAS A HUGE CHALLENGE, BUT--

77

00:03:42,066 --> 00:03:43,900

YOU CAN'T SEE IT
IN THIS PICTURE,

78

00:03:43,900 --> 00:03:46,033

BUT THE ROOF IS
A 1/2 A MEGAWATT POWER PLANT

79

00:03:46,033 --> 00:03:49,233

AND LOTS
OF COOL INNOVATION.

80

00:03:49,233 --> 00:03:52,433

BUT WE--WE TRY TO PRACTICE
WHAT WE PREACH

81

00:03:52,433 --> 00:03:56,066

WITH OUR--
WITH OUR ENTIRE ENVIRONMENT.

82

00:03:58,433 --> 00:04:01,866

I'M GONNA TALK MOSTLY ABOUT
THE INNER CONVERSION

83

00:04:01,866 --> 00:04:04,666

OF THE DIGITAL
AND BIOLOGICAL WORLDS.

84

00:04:06,500 --> 00:04:10,166

KIDS THAT GROW UP
IN THE DIGITAL WORLD

85

00:04:10,166 --> 00:04:14,200

THINK NOTHING OF THIS,
AND IT'S PRETTY OBVIOUS.

86

00:04:14,200 --> 00:04:17,133

IT TOOK A WHILE TO CONVINC
AN OLD GUY LIKE PETE

87

00:04:17,133 --> 00:04:19,666

THIS WAS IMPORTANT,
BUT YOU SEE HE GETS IT NOW.

88

00:04:19,666 --> 00:04:21,400

[laughter]

89

00:04:21,400 --> 00:04:23,833

AND SO THAT'S REALLY IMPORTANT
FOR THE--

90

00:04:23,833 --> 00:04:26,800

I THINK THE FUTURE
OF--OF NASA.

91

00:04:26,800 --> 00:04:29,100

SO WHEN WE READ
THE GENETIC CODE,

92

00:04:29,100 --> 00:04:31,433

WE CONVERT
THIS 4-LETTER SYSTEM

93

00:04:31,433 --> 00:04:33,600

INTO THE 1s AND 0s
IN THE COMPUTER,

94

00:04:33,600 --> 00:04:37,433

AND THIS HAS BEEN GOING ON
FOR QUITE SOME TIME.

95

00:04:37,433 --> 00:04:41,900

IT REALLY STARTED WITH
THE FIRST HUMAN GENE IN 1977,

96

00:04:41,900 --> 00:04:44,566

FIRST VIRUSES

IN THE LATE '70s,

97

00:04:44,566 --> 00:04:46,566

BUT IT WAS THE FIRST
LIVING ORGANISM

98

00:04:46,566 --> 00:04:49,900

THAT MY TEAM SEQUENCED
IN 1995

99

00:04:49,900 --> 00:04:53,933

THAT STARTED TO CHANGE
THE INFORMATION REVOLUTION,

100

00:04:53,933 --> 00:04:55,533

AT LEAST IN BIOLOGY.

101

00:04:55,533 --> 00:04:57,900

AND IT SCALED UP
QUITE QUICKLY

102

00:04:57,900 --> 00:05:02,000

SO WE COULD GO FROM
A 1.8 MILLION BASE PAIR GENOME

103

00:05:02,000 --> 00:05:04,433

FIVE YEARS LATER

104

00:05:04,433 --> 00:05:07,933

TO DO THE FIRST DRAFT
OF THE HAPLOID HUMAN GENOME

105

00:05:07,933 --> 00:05:09,900

AT 3 BILLION LETTERS.

106

00:05:09,900 --> 00:05:12,466

AND THE BREAKTHROUGHS
WERE MOSTLY STRATEGY

107

00:05:12,466 --> 00:05:14,400
AND MATHEMATICAL,

108

00:05:14,400 --> 00:05:17,833
NOT NECESSARILY
IN ANY TECHNOLOGY.

109

00:05:17,833 --> 00:05:21,966
BUT YOU'LL SEE,
THE TOOLS HAVE CHANGED A LOT.

110

00:05:21,966 --> 00:05:24,833
IN 1999,
EVERYBODY THOUGHT

111

00:05:24,833 --> 00:05:28,966
A 1 1/2 TERAFLP COMPUTER
WAS BIG.

112

00:05:28,966 --> 00:05:32,666
AND IT TOOK BUILDING
THIS UNIQUE COMPUTER

113

00:05:32,666 --> 00:05:34,800
TO BE ABLE TO ASSEMBLE
THE FIRST VERSION

114

00:05:34,800 --> 00:05:36,600
OF THE HUMAN GENOME.

115

00:05:36,600 --> 00:05:39,000
AND YOU'LL SEE IN A MINUTE,

116

00:05:39,000 --> 00:05:41,100
IF YOU HAD TO PAY
\$50 MILLION

117

00:05:41,100 --> 00:05:43,000
FOR A 1 1/2 TERAFLP COMPUTER--

118

00:05:43,000 --> 00:05:45,966

ANYBODY WANTS TO DO THAT,
I'M HAPPY TO SELL YOU ONE--

119

00:05:45,966 --> 00:05:47,433

[laughter]

120

00:05:47,433 --> 00:05:51,133

BUT FORTUNATELY,
COMPUTING HAS CHANGED

121

00:05:51,133 --> 00:05:55,433

AS RAPIDLY AS THE TECHNOLOGY
IN THIS SPACE.

122

00:05:55,433 --> 00:05:58,366

AT CELERA, TO DO THE FIRST
VERSION OF THE HUMAN GENOME,

123

00:05:58,366 --> 00:06:01,100

WE HAD AN ENTIRE BUILDING
FILLED WITH MACHINES

124

00:06:01,100 --> 00:06:03,833

THAT LOOKED LIKE THIS.

125

00:06:03,833 --> 00:06:06,600

AND IT TOOK NINE MONTHS

126

00:06:06,600 --> 00:06:08,966

FOR THESE 350 MACHINES

127

00:06:08,966 --> 00:06:13,933

TO SEQUENCE THE FIRST VERSION
OF THE HUMAN GENOME.

128

00:06:13,933 --> 00:06:18,066

SO THAT'S BARELY
15 YEARS AGO.

129

00:06:18,066 --> 00:06:20,400

OVER TIME WE SCALED THIS UP
AND IN 2007

130

00:06:20,400 --> 00:06:23,966

PUBLISHED
THE FIRST DIPLOID GENOME.

131

00:06:23,966 --> 00:06:27,400

WE ALL HAVE
TWO SETS OF CHROMOSOMES.

132

00:06:27,400 --> 00:06:30,366

WE GET HALF
FROM EACH OF OUR PARENTS.

133

00:06:30,366 --> 00:06:32,766

AND IT WASN'T UNTIL 2007

134

00:06:32,766 --> 00:06:35,200

THAT WE ACTUALLY SAW
THE COMPLETE VERSION

135

00:06:35,200 --> 00:06:37,366

OF THE HUMAN GENOME.

136

00:06:37,366 --> 00:06:39,933

BUT THE--THE CHALLENGE GOES
FAR FURTHER MATHEMATICALLY

137

00:06:39,933 --> 00:06:42,500

IN JUST ASSEMBLING THESE,

138

00:06:42,500 --> 00:06:45,600

AND WE'VE NOW SCALED THIS UP
A WHOLE LOT MORE

139

00:06:45,600 --> 00:06:49,100

AT A NEW ENTERPRISE
CALLED HUMAN LONGEVITY

140

00:06:49,100 --> 00:06:51,233
WHERE THE CHALLENGE IS

141

00:06:51,233 --> 00:06:54,033
TO SEE IF WE CAN PREDICT

142

00:06:54,033 --> 00:06:56,700
FROM YOUR GENETIC CODE

143

00:06:56,700 --> 00:07:00,166
ALMOST EVERYTHING
ABOUT YOUR LIFE.

144

00:07:00,166 --> 00:07:02,900
PETE AND I HAVE JOKED
ABOUT THE MOVIE "GATTACA."

145

00:07:02,900 --> 00:07:05,866
SOME PEOPLE THOUGHT
THAT WAS A GREAT MOVIE,

146

00:07:05,866 --> 00:07:08,433
TRYING TO PREDICT
FROM THE GENOME

147

00:07:08,433 --> 00:07:11,500
WHO SHOULD GO INTO SPACE
AND WHO SHOULDN'T

148

00:07:11,500 --> 00:07:14,566
FOR LONG-TERM SPACE TRAVEL.

149

00:07:14,566 --> 00:07:19,000
AND THE HERO STOLE SOMEBODY
ELSE'S GENETIC IDENTITY.

150

00:07:19,000 --> 00:07:21,166
HE WAS SOMEBODY WHO WAS
LIKELY TO DIE IN SIX MONTHS

151
00:07:21,166 --> 00:07:22,966
FROM CARDIAC FAILURE,

152
00:07:22,966 --> 00:07:24,933
SO IF YOU'RE RUNNING
A SPACE PROGRAM,

153
00:07:24,933 --> 00:07:27,066
YOU DON'T REALLY
WANT THAT TO HAPPEN,

154
00:07:27,066 --> 00:07:29,633
AND YOU'D LIKE TO BE ABLE
TO PREDICT THESE THINGS.

155
00:07:29,633 --> 00:07:32,566
BUT ALSO, YOU'D LIKE TO BE ABLE
TO PREDICT THAT FOR YOURSELF,

156
00:07:32,566 --> 00:07:35,433
ESPECIALLY IF YOU CAN DO IT
EARLY ENOUGH

157
00:07:35,433 --> 00:07:37,533
TO DO SOMETHING ABOUT IT.

158
00:07:37,533 --> 00:07:39,766
SO WHAT'S CHANGED?

159
00:07:39,766 --> 00:07:43,066
NOW, INSTEAD
OF 300 MACHINES

160
00:07:43,066 --> 00:07:45,366
AND NINE MONTHS
PER GENOME,

161

00:07:45,366 --> 00:07:47,333

WE HAVE THESE NEW MACHINES

162

00:07:47,333 --> 00:07:51,400

THAT EACH ONE CAN CRANK OUT,
EVERY TWO DAYS,

163

00:07:51,400 --> 00:07:53,366

16 GENOMES.

164

00:07:53,366 --> 00:07:55,266

UH...

165

00:07:55,266 --> 00:08:00,066

IT'S CALLED
ILLUMINA HISEQ X TEN.

166

00:08:00,066 --> 00:08:02,366

WE HAVE FOUR OF THESE,

167

00:08:02,366 --> 00:08:04,733

WHICH WILL ENABLE US
TO DO ON THE ORDER

168

00:08:04,733 --> 00:08:09,100

OF 80,000 TO 100,000 GENOMES
A YEAR

169

00:08:09,100 --> 00:08:11,100

INSTEAD OF ONE
IN NINE MONTHS.

170

00:08:11,100 --> 00:08:14,633

SO THAT'S
A PRETTY BIG CHANGE.

171

00:08:14,633 --> 00:08:17,333

AND THESE MACHINES GENERATE

A LOT OF DATA

172

00:08:17,333 --> 00:08:20,366

JUST GETTING THESE LITTLE PIECES
OF PRIMARY DATA

173

00:08:20,366 --> 00:08:24,200

THAT WE HAVE TO PUT TOGETHER
TO REASSEMBLE THE GENOME.

174

00:08:24,200 --> 00:08:26,100

IT'S NOT ADEQUATE TECHNOLOGY
RIGHT NOW

175

00:08:26,100 --> 00:08:28,600

FOR ALL THE THINGS
WE WANT TO DO,

176

00:08:28,600 --> 00:08:30,566

BUT IT IS CHANGING.

177

00:08:30,566 --> 00:08:34,433

AND THAT GIANT ROOM ABOUT
THE SIZE OF THIS AUDITORIUM

178

00:08:34,433 --> 00:08:36,300

FOR OUR
1 1/2 TERAFLUP COMPUTER

179

00:08:36,300 --> 00:08:38,266

CAN NOW BE REPLACED

180

00:08:38,266 --> 00:08:41,600

BY A CARD FOR YOUR PC

181

00:08:41,600 --> 00:08:44,866

AND KEEPS GETTING SMALLER
AND FASTER.

182

00:08:44,866 --> 00:08:49,166
BUT IT'S STILL ONE OF THE
BIGGEST COMPUTATIONAL CHALLENGES

183
00:08:49,166 --> 00:08:52,500
OF WAYS EVEN TO PUT
AND SEPARATE

184
00:08:52,500 --> 00:08:55,066
YOUR PARENTAL CHROMOSOMES
FROM EACH OTHER.

185
00:08:55,066 --> 00:08:59,333
ONE WAY WE DID THIS EARLY ON
AT THE VENTER INSTITUTE--

186
00:08:59,333 --> 00:09:02,300
WE DEVELOPED
SINGLE-CELL SEQUENCING.

187
00:09:02,300 --> 00:09:05,633
SO WE CAN DO A GENOME
ON A SINGLE BACTERIAL CELL,

188
00:09:05,633 --> 00:09:07,500
A SINGLE HUMAN CELL,

189
00:09:07,500 --> 00:09:09,400
AND THIS DOES CELL SORTING
TO DO THIS.

190
00:09:09,400 --> 00:09:12,766
AND TO SEPARATE THE GENOME
INTO HAPLOTYPES,

191
00:09:12,766 --> 00:09:16,933
WE ACTUALLY SEQUENCED
INDIVIDUAL SPERM CELLS.

192
00:09:16,933 --> 00:09:19,033

WE JUST
SIMPLY SEPARATED ONE,

193
00:09:19,033 --> 00:09:21,233
PULLED OUT
INDIVIDUAL SPERM CELLS,

194
00:09:21,233 --> 00:09:24,800
AND SEQUENCED THE GENOME.

195
00:09:24,800 --> 00:09:27,200
YOU PROBABLY--
EVEN THOUGH A LOT OF YOU

196
00:09:27,200 --> 00:09:30,500
ARE--ARE PHYSICISTS,
YOU PROBABLY KNOW YOUR SPERM,

197
00:09:30,500 --> 00:09:32,966
IF YOU'RE MALES,
ONLY HAS HALF THE GENOME,

198
00:09:32,966 --> 00:09:35,700
AND IF YOU'RE FEMALE, THE EGGS
ONLY HAVE HALF THE GENOME.

199
00:09:35,700 --> 00:09:38,666
IF NOT, YOU JUST LEARNED
SOMETHING REALLY IMPORTANT

200
00:09:38,666 --> 00:09:40,900
ABOUT THE NEXT STAGES
OF YOUR LIFE.

201
00:09:40,900 --> 00:09:43,166
[laughter]

202
00:09:43,166 --> 00:09:45,466
BUT IT TURNS OUT,
NO TWO SPERM CELLS

203

00:09:45,466 --> 00:09:49,200

OR TWO EGG CELLS
HAVE THE SAME GENETIC CODE,

204

00:09:49,200 --> 00:09:52,566

AND IT'S BECAUSE THERE'S RANDOM
BREAKS IN THE CHROMOSOMES

205

00:09:52,566 --> 00:09:54,533

AND CROSSOVERS.

206

00:09:54,533 --> 00:09:57,566

SO YOU HAVE TO SEQUENCE,
YOU KNOW,

207

00:09:57,566 --> 00:10:00,600

SIX OR A DOZEN SPERM CELLS

208

00:10:00,600 --> 00:10:03,066

TO GET THE COMPLETE
HAPLOTYPE PHASING

209

00:10:03,066 --> 00:10:06,500

OF HAVING THE CHROMOSOME
SEPARATED.

210

00:10:06,500 --> 00:10:08,233

SO THAT'S A PHYSICAL WAY
TO DO IT,

211

00:10:08,233 --> 00:10:10,500

REQUIRES A LOT MORE
SEQUENCING.

212

00:10:10,500 --> 00:10:12,466

WE'RE TRYING TO FIND
NEW MATHEMATICAL WAYS

213

00:10:12,466 --> 00:10:14,700
TO MAKE THIS HAPPEN

214
00:10:14,700 --> 00:10:16,900
EVEN FASTER

215
00:10:16,900 --> 00:10:19,566
FROM THE HIGH-THROUGHPUT
GENOME SEQUENCING.

216
00:10:19,566 --> 00:10:21,433
BUT IT'S IMPORTANT
IN THE SENSE

217
00:10:21,433 --> 00:10:24,666
THAT EVERY ONE OF YOU, I'M SURE,
HAS ASKED THE QUESTION--

218
00:10:24,666 --> 00:10:28,366
DID YOU GET THIS TRAIT
OR THAT TRAIT

219
00:10:28,366 --> 00:10:30,000
FROM YOUR FATHER
OR FROM YOUR MOTHER

220
00:10:30,000 --> 00:10:32,366
OR THEIR SIDE OF THE FAMILY?

221
00:10:32,366 --> 00:10:34,166
DID YOU...

222
00:10:34,166 --> 00:10:36,333
YOU KNOW, YOUR SPOUSE
WAS THE ONE WHO CONTRIBUTED

223
00:10:36,333 --> 00:10:37,933
THE BAD TRAIT
TO YOUR KIDS.

224

00:10:37,933 --> 00:10:39,566

YOU ONLY CONTRIBUTED
THE GOOD ONES.

225

00:10:39,566 --> 00:10:41,866

SO EVERYBODY DOES TRACK
THESE THINGS.

226

00:10:41,866 --> 00:10:43,966

BUT IT BECOMES IMPORTANT
IN UNDERSTANDING

227

00:10:43,966 --> 00:10:46,433

YOUR GENETIC HISTORY

228

00:10:46,433 --> 00:10:48,233

AND YOUR GENETIC FUTURE

229

00:10:48,233 --> 00:10:51,000

TO, IN FACT, KNOW...

230

00:10:51,000 --> 00:10:53,100

BY KNOWING YOUR MOTHER'S
GENETIC HISTORY

231

00:10:53,100 --> 00:10:54,833

AND YOUR FATHER'S
GENETIC HISTORY

232

00:10:54,833 --> 00:10:57,166

AND WHICH PARTS
CONTRIBUTED WHAT

233

00:10:57,166 --> 00:11:00,066

BECOMES PART OF THE BIG
MATHEMATICAL PUZZLE

234

00:11:00,066 --> 00:11:02,166

FOR DE-CONVOLUTING

THIS INFORMATION.

235

00:11:02,166 --> 00:11:05,466
AND IT TURNS OUT
FOR ALMOST EVERY GENE

236

00:11:05,466 --> 00:11:09,166
YOU INHERITED
DIFFERENT VARIANTS

237

00:11:09,166 --> 00:11:12,200
FROM YOUR FATHER
AND FROM YOUR MOTHER.

238

00:11:12,200 --> 00:11:15,366
AND WHAT'S A GENE OF CONSEQUENCE
FOR A UNIQUE TRAIT

239

00:11:15,366 --> 00:11:19,566
OR FOR A DISEASE--

240

00:11:19,566 --> 00:11:21,633
WHAT ARE CALLED
COMPOUND HETEROZYGOTES--

241

00:11:21,633 --> 00:11:24,433
ARE FAR MORE PREDICTIVE
OF REALITY

242

00:11:24,433 --> 00:11:26,966
THAN ANYTHING BEING DONE TODAY
IN GENETICS

243

00:11:26,966 --> 00:11:30,866
JUST MEASURING SINGLE GENETIC
POLYMORPHISMS.

244

00:11:30,866 --> 00:11:34,466
SO WHEN WE LOOK AT
COMPOUND HETEROZYGOTES

245

00:11:34,466 --> 00:11:37,166

WHERE YOU HAVE
TWO INDEPENDENT CHANGES

246

00:11:37,166 --> 00:11:39,600

IN THE SAME GENE,
ONE FROM EACH PARENT,

247

00:11:39,600 --> 00:11:42,733

IT'S FAR MORE PREDICTIVE
OF THE PHENOTYPE

248

00:11:42,733 --> 00:11:45,866

PARTICULARLY FOR RISK ALLELES
ASSOCIATED WITH DISEASE.

249

00:11:45,866 --> 00:11:48,366

SO IT'S NOT JUST OF
THEORETICAL INTEREST,

250

00:11:48,366 --> 00:11:52,000

IT'S OF REAL CRITICAL INTEREST
GOING FORWARD TO DO THIS.

251

00:11:52,000 --> 00:11:54,533

AND SO THE--
THESE COMPOUND MUTATIONS

252

00:11:54,533 --> 00:11:56,600

OR COMPOUND HETEROZYGOTES

253

00:11:56,600 --> 00:11:59,266

ARE NOT BEING MEASURED AT ALL
IN SCIENCE

254

00:11:59,266 --> 00:12:02,000

BECAUSE THERE'S BEEN
NO WAY TO DO IT

255
00:12:02,000 --> 00:12:06,333
WITHOUT SEPARATING
THE HAPLOTYPES OF THE GENOMES.

256
00:12:07,566 --> 00:12:09,666
WE'RE TRYING TO BUILD
A DATABASE

257
00:12:09,666 --> 00:12:11,333
OF 1 TO 2 MILLION GENOMES

258
00:12:11,333 --> 00:12:13,766
OVER THE NEXT FEW YEARS,

259
00:12:13,766 --> 00:12:15,766
AS FAST AS WE CAN.

260
00:12:15,766 --> 00:12:18,266
WE ANNOUNCED THIS
STARTING WITH

261
00:12:18,266 --> 00:12:20,766
THE MOORES CANCER CENTER
IN SAN DIEGO,

262
00:12:20,766 --> 00:12:22,833
OF SEQUENCING THE GENOME
OF EVERY PATIENT

263
00:12:22,833 --> 00:12:25,366
THAT COMES
TO THAT HOSPITAL

264
00:12:25,366 --> 00:12:29,000
BUT ALSO SEQUENCING THE GENOMES
ON THEIR TUMORS.

265
00:12:29,000 --> 00:12:32,200
AND TUMOR GENOME SEQUENCING,

266

00:12:32,200 --> 00:12:35,766

NOW TRACKING WHAT ARE CALLED
DRIVER MUTATIONS,

267

00:12:35,766 --> 00:12:38,333

ARE PROBABLY THE MOST IMPORTANT
THING YOU CAN KNOW

268

00:12:38,333 --> 00:12:40,733

IF YOU GET
THE UNFORTUNATE DIAGNOSIS

269

00:12:40,733 --> 00:12:43,333

OF A DIFFERENT TYPE
OF CANCER,

270

00:12:43,333 --> 00:12:46,266

FOR EXAMPLE,
A LUNG CANCER.

271

00:12:46,266 --> 00:12:49,400

THERE'S VARIATIONS
IN AN ALK GENE

272

00:12:49,400 --> 00:12:53,200

THAT ROUGHLY 3% OF PEOPLE
WITH LUNG CANCER

273

00:12:53,200 --> 00:12:55,633

HAVE THIS GENETIC VARIATION,

274

00:12:55,633 --> 00:12:57,833

THAT IF YOU HAVE
THAT VARIATION,

275

00:12:57,833 --> 00:13:02,600

PFIZER HAS A DRUG
THAT HAS A VERY HIGH CHANCE

276

00:13:02,600 --> 00:13:04,666

OF TREATING
YOUR LUNG CANCER.

277

00:13:04,666 --> 00:13:06,200

[man coughs]

278

00:13:06,200 --> 00:13:08,566

SO OBVIOUSLY, IF YOU'RE COUGHING
AND HAVE LUNG CANCER...

279

00:13:08,566 --> 00:13:10,333

[laughter]

280

00:13:10,333 --> 00:13:13,966

THE--THE MOST IMPORTANT THING
YOU CAN KNOW IS YOUR GENOME,

281

00:13:13,966 --> 00:13:16,433

AND THIS IS NOW
STARTING TO HAPPEN

282

00:13:16,433 --> 00:13:18,300

WITH MORE AND MORE TUMORS.

283

00:13:18,300 --> 00:13:21,266

AND IT'S CAUGHT ON JUST
IN THE LAST ONE TO THREE YEARS

284

00:13:21,266 --> 00:13:24,566

BECAUSE THIS IS STARTING
TO ACTUALLY CHANGE

285

00:13:24,566 --> 00:13:26,733

CLINICAL PRACTICE.

286

00:13:26,733 --> 00:13:28,433

THE COUNTER SIDE OF THIS

287

00:13:28,433 --> 00:13:30,866

IS THE PHARMACEUTICAL INDUSTRY
FOUND

288

00:13:30,866 --> 00:13:33,466

HOW TO STILL TURN THESE
INTO BLOCKBUSTERS

289

00:13:33,466 --> 00:13:36,866

BY CHARGING
ALMOST \$10,000 A MONTH

290

00:13:36,866 --> 00:13:38,866

FOR TREATMENTS,

291

00:13:38,866 --> 00:13:43,900

BECAUSE THEY HAVE A SMALLER
NUMBER OF PATIENTS BUYING THESE.

292

00:13:43,900 --> 00:13:46,100

BUT IF YOU HAVE
LUNG CANCER

293

00:13:46,100 --> 00:13:47,666

AND THEIR DRUG
CAN CURE IT,

294

00:13:47,666 --> 00:13:50,600

YOU'RE PROBABLY HAPPY
TO SEE THAT.

295

00:13:50,600 --> 00:13:52,733

NASA'S AN ORGANIZATION

296

00:13:52,733 --> 00:13:54,633

THAT IS FAMOUS

297

00:13:54,633 --> 00:13:59,166

FOR DOING

PHENOTYPE SELECTION.

298

00:13:59,166 --> 00:14:02,166

THEY DON'T CALL IT
GENETIC SELECTION,

299

00:14:02,166 --> 00:14:03,866

'CAUSE THAT--
THAT WAS A WORD

300

00:14:03,866 --> 00:14:05,766

THAT PROBABLY SCARED THEM
A LITTLE BIT,

301

00:14:05,766 --> 00:14:07,500

AND THEY DIDN'T PROBABLY
REALLY KNOW

302

00:14:07,500 --> 00:14:08,933

THEY WERE DOING
GENETIC SELECTION.

303

00:14:08,933 --> 00:14:11,633

BUT WHEN YOU SCREEN ANY
POPULATION FOR DIFFERENT TRAITS

304

00:14:11,633 --> 00:14:13,666

FOR SUCCESS--

305

00:14:13,666 --> 00:14:15,133

SUCH AS THE OLYMPICS,

306

00:14:15,133 --> 00:14:18,800

THE OLYMPICS IS THE ULTIMATE
IN GENETIC SELECTION--

307

00:14:18,800 --> 00:14:22,166

PEOPLE WITH THE BEST GENOMES
AND THE BEST TRAITS

308

00:14:22,166 --> 00:14:25,100

IN DIFFERENT FIELDS,
DEPENDENT ON FAST MUSCLE TWITCH

309

00:14:25,100 --> 00:14:28,700

OR ACCELERATION GENES,
ET CETERA,

310

00:14:28,700 --> 00:14:32,500

END UP BEING THE ONE
TO EXCEL IN SPORTS,

311

00:14:32,500 --> 00:14:35,233

AND NASA HAD DIFFERENT
SELECTION CRITERIA.

312

00:14:35,233 --> 00:14:37,500

BUT IF YOU'RE GONNA
START SCREENING,

313

00:14:37,500 --> 00:14:38,966

THERE'S A NUMBER
OF TRAITS--

314

00:14:38,966 --> 00:14:42,100

I JUST LISTED
A FEW OF THEM HERE--

315

00:14:42,100 --> 00:14:44,266

THAT MIGHT BE IMPORTANT

316

00:14:44,266 --> 00:14:47,200

FOR LONG-TERM SPACE TRAVEL.

317

00:14:47,200 --> 00:14:49,466

FOR EXAMPLE,
BEING ABLE TO DO

318

00:14:49,466 --> 00:14:53,600

VERY EFFECTIVE DNA REPAIR
AFTER RADIATION DAMAGE

319

00:14:53,600 --> 00:14:55,566

MAKES THE DIFFERENCE
IN WHETHER YOU GET CANCER

320

00:14:55,566 --> 00:14:57,166

OR DON'T GET CANCER.

321

00:14:57,166 --> 00:15:00,233

OBVIOUSLY, A VERY STRONG
IMMUNE SYSTEM.

322

00:15:00,233 --> 00:15:02,133

ALL THESE THINGS--
LACK OF HAIR,

323

00:15:02,133 --> 00:15:04,566

I THINK IS ONE OF
THE MOST IMPORTANT TRAITS...

324

00:15:04,566 --> 00:15:07,266

[laughter]

325

00:15:07,266 --> 00:15:09,966

BUT THESE ARE THINGS

326

00:15:09,966 --> 00:15:12,300

THAT CAN BE MEASURED
IN THE FUTURE

327

00:15:12,300 --> 00:15:14,533

STRAIGHT FROM THE GENOME.

328

00:15:14,533 --> 00:15:17,700

AND SO IT'S--
IT'S SOMETHING TO THINK ABOUT.

329

00:15:17,700 --> 00:15:21,166
BUT WE DON'T JUST HAVE
OUR GENOME.

330
00:15:21,166 --> 00:15:25,566
WE HAVE, AND ARE DEPENDENT ON,
A LARGE REPERTOIRE OF BACTERIA

331
00:15:25,566 --> 00:15:28,466
THAT LIVE ON
AND WITHIN US.

332
00:15:28,466 --> 00:15:32,600
IT DOESN'T MATTER HOW OFTEN
YOU WASH YOUR HANDS,

333
00:15:32,600 --> 00:15:37,633
YOU HAVE ABOUT 3,000
UNIQUE SPECIES

334
00:15:37,633 --> 00:15:41,500
CONTRIBUTING AS MANY AS
10 MILLION ADDITIONAL GENES

335
00:15:41,500 --> 00:15:44,400
TO OUR BIOLOGICAL REPERTOIRE.

336
00:15:44,400 --> 00:15:46,300
THIS IS CALLED
THE MICROBIOME.

337
00:15:46,300 --> 00:15:50,300
AND JUST THINK ABOUT

338
00:15:50,300 --> 00:15:52,400
NEXT TIME YOU'RE--

339
00:15:52,400 --> 00:15:54,100
IT'S NOT A WORK-RELATED THING,
HOPEFULLY.

340

00:15:54,100 --> 00:15:55,666

KISSING SOMEBODY
OR SOMETHING ELSE,

341

00:15:55,666 --> 00:15:59,166

IT'S A THOUSAND
DIFFERENT SPECIES

342

00:15:59,166 --> 00:16:02,266

THAT YOU HAVE OR THEY HAVE
IN THEIR MOUTH.

343

00:16:02,266 --> 00:16:04,400

BUT THINK ABOUT
EVERY ASTRONAUT

344

00:16:04,400 --> 00:16:06,966

THAT GOES UP
TO THE SPACE STATION

345

00:16:06,966 --> 00:16:10,400

IS CARRYING ON THE ORDER
OF 3,000 UNIQUE SPECIES

346

00:16:10,400 --> 00:16:12,066

WITH THEM,

347

00:16:12,066 --> 00:16:14,066

SOME THAT MIGHT INFECT
THEIR COLLEAGUES,

348

00:16:14,066 --> 00:16:16,033

EVEN THOUGH THEY MAY NOT
NECESSARILY INFECT

349

00:16:16,033 --> 00:16:18,733

THAT PERSON CARRYING THEM.

350

00:16:18,733 --> 00:16:21,433
AND THEY'RE AN IMPORTANT PART
OF BIOLOGY.

351
00:16:21,433 --> 00:16:23,733
SO PART OF WHAT WE'RE DOING
AT HUMAN LONGEVITY

352
00:16:23,733 --> 00:16:26,266
IS GOING TO BE SEQUENCING
THE MICROBIOME

353
00:16:26,266 --> 00:16:28,300
ON AS MANY PEOPLE
AS WE CAN.

354
00:16:28,300 --> 00:16:30,566
THESE ARE JUST A FEW
OF THE DISEASES

355
00:16:30,566 --> 00:16:33,733
THAT HAVE BEEN ASSOCIATED WITH
CHANGES IN THE MICROBIOME.

356
00:16:33,733 --> 00:16:36,300
BUT ALSO THINGS LIKE
ESOPHAGEAL CANCER,

357
00:16:36,300 --> 00:16:38,333
STOMACH CANCER,

358
00:16:38,333 --> 00:16:42,700
ALL ASSOCIATED VERY CLEARLY
WITH CHANGES IN BACTERIA.

359
00:16:42,700 --> 00:16:46,033
SO WE USE A DIFFERENT
ILLUMINA MACHINE

360
00:16:46,033 --> 00:16:48,233

AND WE CAN MULTIPLEX
THESE SAMPLES

361
00:16:48,233 --> 00:16:50,266
BY LAYERING THEM
ON EACH OTHER,

362
00:16:50,266 --> 00:16:52,800
SO A SINGLE MACHINE
CAN PROCESS

363
00:16:52,800 --> 00:16:55,066
ABOUT 166 SAMPLES.

364
00:16:55,066 --> 00:16:57,533
SO YOU CAN SEE, JUST BY ADDING
LOTS OF MACHINES ON,

365
00:16:57,533 --> 00:17:01,466
THIS ADDS UP QUITE QUICKLY.

366
00:17:01,466 --> 00:17:04,233
I ACTUALLY PROPOSED
FOR THE FIRST TIME HERE

367
00:17:04,233 --> 00:17:06,200
FOUR YEARS AGO

368
00:17:06,200 --> 00:17:08,366
THAT WE MIGHT WANT
TO THINK ABOUT DESIGNING

369
00:17:08,366 --> 00:17:11,133
A SYNTHETIC MICROBIOME.

370
00:17:11,133 --> 00:17:14,966
AND NOW THAT NASA'S BEEN
INCREASING THE DISCUSSIONS

371

00:17:14,966 --> 00:17:17,100
ABOUT GOING TO MARS

372
00:17:17,100 --> 00:17:19,766
AND ELON MUSK
IS GOING TO GO THERE...

373
00:17:22,400 --> 00:17:24,566
WE GOTTA THINK ABOUT
THE IMPLICATIONS

374
00:17:24,566 --> 00:17:26,966
OF EACH PERSON CARRYING

375
00:17:26,966 --> 00:17:29,466
ALL THESE THOUSANDS
OF UNIQUE SPECIES WITH THEM

376
00:17:29,466 --> 00:17:31,433
TO ANOTHER PLANET,

377
00:17:31,433 --> 00:17:35,233
'CAUSE ONCE THEY ESTABLISH
THERE, WE WON'T GET RID OF THEM.

378
00:17:35,233 --> 00:17:37,866
WE MIGHT LIKE TO CHOOSE
WHAT WE ESTABLISH THERE,

379
00:17:37,866 --> 00:17:41,333
AND--BUT IT TURNS OUT

380
00:17:41,333 --> 00:17:44,100
THE PHARMACEUTICAL INDUSTRY IS
ALL OF A SUDDEN VERY INTERESTED

381
00:17:44,100 --> 00:17:48,433
IN SYNTHETIC MICROBIOMES,
AS WELL.

382

00:17:48,433 --> 00:17:53,333

AND BY CHANGING SPECIFICALLY
THE MICROBES

383

00:17:53,333 --> 00:17:56,066

IN YOUR GI SYSTEM,
ON YOUR SKIN,

384

00:17:56,066 --> 00:18:00,800

CAN VERY MUCH CHANGE
YOUR BIOLOGY.

385

00:18:00,800 --> 00:18:04,200

SO WE MIGHT WANT
TO THINK ABOUT

386

00:18:04,200 --> 00:18:07,400

HAVING A DEFINED MICROBIOME

387

00:18:07,400 --> 00:18:09,333

FOR EACH INDIVIDUAL

388

00:18:09,333 --> 00:18:13,200

BEFORE CONTAMINATING
ENTIRE PLANETS

389

00:18:13,200 --> 00:18:15,833

WITH DISEASE-CAUSING MICROBES.

390

00:18:15,833 --> 00:18:18,700

AND EACH OF US HAS A DIFFERENT
GENETIC REPERTOIRE

391

00:18:18,700 --> 00:18:20,933

FOR THE MICROBES
THAT WE TOLERATE

392

00:18:20,933 --> 00:18:23,500

VERSUS CAUSE DISEASE.

393

00:18:23,500 --> 00:18:26,033
ABOUT 5% OF YOU
ARE TOTALLY RESISTANT

394

00:18:26,033 --> 00:18:27,700
TO HIV INFECTIONS,

395

00:18:27,700 --> 00:18:31,200
JUST DUE TO A SINGLE LETTER
CHANGE IN ONE GENE,

396

00:18:31,200 --> 00:18:34,200
BUT THAT DOESN'T MEAN
YOU COULDN'T CARRY IT

397

00:18:34,200 --> 00:18:36,600
AND GIVE IT TO OTHERS.

398

00:18:36,600 --> 00:18:38,866
SO ASIDE FROM
THE MICROBIOME,

399

00:18:38,866 --> 00:18:43,266
WE'RE ALSO MEASURING 2,400
CHEMICALS IN THE BLOODSTREAM.

400

00:18:43,266 --> 00:18:45,100
IT'S CALLED
THE METABOLOME,

401

00:18:45,100 --> 00:18:47,866
AND WE'RE DOING THIS
WITH A COMPANY

402

00:18:47,866 --> 00:18:50,033
CALLED METABOLOMICS
IN NORTH CAROLINA.

403

00:18:50,033 --> 00:18:53,433
AND IT TURNS OUT, 2,400
IS ABOUT THE HUMAN REPERTOIRE.

404
00:18:53,433 --> 00:18:55,800
EACH OF US CAN SYNTHESIZE

405
00:18:55,800 --> 00:18:58,433
AROUND 2,400
DIFFERENT CHEMICALS.

406
00:18:59,933 --> 00:19:03,800
AND SO YOU CAN INFER

407
00:19:03,800 --> 00:19:05,666
BIOCHEMICAL PATHWAYS

408
00:19:05,666 --> 00:19:08,333
BY THE METABOLITES
THAT YOU HAVE.

409
00:19:08,333 --> 00:19:11,500
THE COMPLICATION IS

410
00:19:11,500 --> 00:19:14,200
WHEN YOU LOOK IN THE BLOODSTREAM
OF PEOPLE

411
00:19:14,200 --> 00:19:16,133
AFTER A MEAL,

412
00:19:16,133 --> 00:19:18,600
ONLY ABOUT 60%
OF THE CHEMICALS

413
00:19:18,600 --> 00:19:20,466
ARE OF HUMAN ORIGIN.

414
00:19:20,466 --> 00:19:23,300

30% ARE FROM ALL
THE DIFFERENT SPECIES

415

00:19:23,300 --> 00:19:25,766
YOU CONSUMED IN YOUR DIET.

416

00:19:25,766 --> 00:19:28,066
BUT 10%,
OR ABOUT 50 CHEMICALS

417

00:19:28,066 --> 00:19:30,966
CIRCULATING THROUGH YOUR BRAIN
RIGHT NOW,

418

00:19:30,966 --> 00:19:33,833
ARE FROM BACTERIAL METABOLITES

419

00:19:33,833 --> 00:19:36,366
OF THE CHEMICALS YOU CONSUMED
IN YOUR DIET

420

00:19:36,366 --> 00:19:38,933
AND OF YOUR HUMAN CHEMICALS.

421

00:19:38,933 --> 00:19:42,166
SO IF WE WANT TO HAVE
DEFINED ENVIRONMENTS

422

00:19:42,166 --> 00:19:43,966
IN SPACE,

423

00:19:43,966 --> 00:19:46,300
NOT ONLY DO YOU WANT TO DEFINE
THE MICROBIOME,

424

00:19:46,300 --> 00:19:48,466
YOU WANT TO DEFINE
THE CHEMICAL INPUTS

425

00:19:48,466 --> 00:19:51,966
BECAUSE THAT WILL DETERMINE
THE OUTPUTS.

426
00:19:51,966 --> 00:19:54,633
AND WE HAVE NO IDEA
WHETHER THESE AFFECT,

427
00:19:54,633 --> 00:19:57,500
POSITIVELY OR NEGATIVELY,
YOUR MENTAL CAPABILITIES.

428
00:19:57,500 --> 00:20:00,500
WE DO KNOW THEY CHANGE
DISEASE OUTCOMES

429
00:20:00,500 --> 00:20:04,000
AND THERE'S LOTS OF DIAGNOSTICS
BASED JUST ON MEASURING

430
00:20:04,000 --> 00:20:06,866
THESE CHEMICALS
IN THE BLOODSTREAM.

431
00:20:06,866 --> 00:20:08,366
THESE ARE JUST A FEW
OF THE THINGS

432
00:20:08,366 --> 00:20:11,966
WE'RE TRYING TO MEASURE
AS PART OF THE HUMAN PHENOTYPE.

433
00:20:13,700 --> 00:20:16,533
WE'RE SETTING UP TO DO
QUANTITATIVE MR--

434
00:20:16,533 --> 00:20:18,500
WHOLE-BODY MRI,

435
00:20:18,500 --> 00:20:21,700

AND A TEAM
AT UC SAN DIEGO

436
00:20:21,700 --> 00:20:24,466
GOT THIS GOING NICELY
WITH A BRAIN,

437
00:20:24,466 --> 00:20:27,433
WHERE WE CAN TAKE
A QUANTITATIVE MRI,

438
00:20:27,433 --> 00:20:29,000
A SET OF IMAGES,

439
00:20:29,000 --> 00:20:31,866
AND REDUCE IT TO
A TABLE OF VOLUMES

440
00:20:31,866 --> 00:20:33,933
OF DIFFERENT REGIONS
OF THE BRAIN.

441
00:20:33,933 --> 00:20:36,466
THIS IS BEING USED TO DIAGNOSE
ALZHEIMER'S DISEASE,

442
00:20:36,466 --> 00:20:38,266
FOR EXAMPLE,

443
00:20:38,266 --> 00:20:40,166
AND CAN BE DONE FAR MORE
ACCURATELY

444
00:20:40,166 --> 00:20:43,066
THAN EVEN
THE BEST PATHOLOGIST.

445
00:20:43,066 --> 00:20:46,500
AND WE'RE GONNA BE LAYERING
LAYER UPON LAYER

446

00:20:46,500 --> 00:20:48,766
OF ALL THIS INFORMATION

447

00:20:48,766 --> 00:20:52,500
USING THE GENOME
AS THE ORGANIZING PRINCIPLES.

448

00:20:52,500 --> 00:20:54,833
THE GOALS ARE--

449

00:20:54,833 --> 00:20:57,666
CAN WE LEARN ENOUGH--
SEE, ALL THESE THINGS,

450

00:20:57,666 --> 00:20:59,933
INCLUDING
EPIGENETIC PHENOMENON,

451

00:20:59,933 --> 00:21:02,566
ALL START WITH
YOUR GENETIC CODE--

452

00:21:02,566 --> 00:21:04,600
CAN WE LEARN ENOUGH
TO ACTUALLY GO BACK

453

00:21:04,600 --> 00:21:07,133
AND START TO MAKE
FUNDAMENTAL PREDICTIONS

454

00:21:07,133 --> 00:21:09,833
STRAIGHT FROM
THAT PRIMARY CODE

455

00:21:09,833 --> 00:21:13,500
WITHOUT HAVING TO MEASURE
ALL THESE OTHER CHANGES?

456

00:21:13,500 --> 00:21:16,533
AND SO THIS--IT'S THIS
NEW INTEGRATIVE APPROACH

457
00:21:16,533 --> 00:21:20,466
TO MEDICINE, TRYING TO MAKE
MEDICINE QUANTITATIVE

458
00:21:20,466 --> 00:21:22,433
FOR THE FIRST TIME EVER

459
00:21:22,433 --> 00:21:26,666
BASED ON ACTUAL,
FACTUAL, MEASURABLE,

460
00:21:26,666 --> 00:21:29,400
ACCURATELY PREDICTABLE
INFORMATION.

461
00:21:29,400 --> 00:21:31,433
IT'S GONNA BE
A BIG CHALLENGE,

462
00:21:31,433 --> 00:21:36,066
BUT THE TECHNOLOGY
HAS ADVANCED ENOUGH,

463
00:21:36,066 --> 00:21:39,033
BOTH IN
THE DNA SEQUENCING SIDE

464
00:21:39,033 --> 00:21:41,200
AND ON THE COMPUTE SIDE,

465
00:21:41,200 --> 00:21:43,500
TO PUT US
RIGHT AT THE THRESHOLD

466
00:21:43,500 --> 00:21:46,400
OF MAKING THIS POSSIBLE.

467

00:21:46,400 --> 00:21:48,133
ALL THESE GET BACK
TO THE QUESTION

468

00:21:48,133 --> 00:21:51,266
OF THE GENETIC CODE

469

00:21:51,266 --> 00:21:53,600
PREDICTING LIFE OUTCOMES

470

00:21:53,600 --> 00:21:55,566
AND PROGRAMMING
LIFE OUTCOMES

471

00:21:55,566 --> 00:21:59,200
AND TRYING TO MEASURE
HOW REAL THAT IS.

472

00:21:59,200 --> 00:22:03,266
SO ONE OF THE APPROACHES
WE TOOK TO THIS EARLY ON

473

00:22:03,266 --> 00:22:07,866
WAS STARTING WITH THE 1s AND 0s
ON THE COMPUTER

474

00:22:07,866 --> 00:22:10,700
TO SEE IF WE COULD
RECAPITULATE LIFE

475

00:22:10,700 --> 00:22:12,800
BY GOING
IN THE OTHER DIRECTION

476

00:22:12,800 --> 00:22:15,633
AND RE-CHEMICALLY MAKING
THE GENETIC CODE

477

00:22:15,633 --> 00:22:19,533
BASED ON THE COMPUTER CODE.

478
00:22:19,533 --> 00:22:22,866
JUST STRAIGHTFORWARD,
BASIC ANSWERS.

479
00:22:22,866 --> 00:22:25,066
BIG QUESTIONS,
YOU KNOW--

480
00:22:25,066 --> 00:22:27,100
DOES DNA CONTAIN
ALL THE NECESSARY INFORMATION

481
00:22:27,100 --> 00:22:29,066
FOR CELLULAR LIFE?

482
00:22:29,066 --> 00:22:30,833
PEOPLE, FOR CENTURIES,

483
00:22:30,833 --> 00:22:34,800
HAVE BEEN LOOKING FOR SOME
VITALISTIC MAGIC COMPONENT,

484
00:22:34,800 --> 00:22:39,100
AND EVEN THOUGH MOST
MODERN SCIENTISTS

485
00:22:39,100 --> 00:22:43,666
THINK THAT VITALISM
WAS DISPROVED CENTURIES AGO...

486
00:22:45,700 --> 00:22:49,866
THERE'S PROBABLY ABOUT 30 OR 40%
OF THE BIOLOGICAL COMMUNITY

487
00:22:49,866 --> 00:22:53,566
ARE WHAT I DESCRIBE
CLOSET VITALIST.

488

00:22:53,566 --> 00:22:56,466

THEY ACTUALLY WANT THERE
TO BE SOMETHING MORE

489

00:22:56,466 --> 00:23:00,300

THAN THIS FACTUAL
CHEMICAL INFORMATION.

490

00:23:00,300 --> 00:23:03,633

AND I THINK THEY'RE
LARGELY DISAPPOINTED.

491

00:23:03,633 --> 00:23:05,800

YOU KNOW, SIMPLE QUESTIONS
LIKE, YOU KNOW,

492

00:23:05,800 --> 00:23:07,933

WHAT IS THE SMALLEST NUMBER
OF GENES

493

00:23:07,933 --> 00:23:12,900

FOR A SELF-REPLICATING CELL?

494

00:23:12,900 --> 00:23:15,000

AND THEN ULTIMATELY
TO ANSWER THESE,

495

00:23:15,000 --> 00:23:18,500

COULD WE DESIGN AND CONSTRUCT
SUCH A GENOME, SUCH A CELL?

496

00:23:18,500 --> 00:23:20,233

AND AS SOON AS WE STARTED
DOWN THIS ROUTE,

497

00:23:20,233 --> 00:23:21,566

WE HAD NEW QUESTIONS,

498

00:23:21,566 --> 00:23:23,266
'CAUSE NOBODY HAD EVER
DONE THIS BEFORE.

499
00:23:23,266 --> 00:23:25,366
WOULD CHEMISTRY
EVEN PERMIT US

500
00:23:25,366 --> 00:23:29,166
TO WRITE LARGE STRETCHES
OF GENETIC CODE?

501
00:23:29,166 --> 00:23:31,166
AND EVEN IF
WE COULD DO THAT,

502
00:23:31,166 --> 00:23:34,600
COULD WE FIND A WAY TO BOOT UP
THIS CHEMICAL SOFTWARE

503
00:23:34,600 --> 00:23:37,400
TO GET A LIVING CELL?

504
00:23:37,400 --> 00:23:39,533
WE STARTED, EARLY ON,

505
00:23:39,533 --> 00:23:41,200
WITH SOMETHING MUCH SMALLER.

506
00:23:41,200 --> 00:23:44,266
WE DECIDED TO START
WITH PHIX174,

507
00:23:44,266 --> 00:23:45,800
'CAUSE IT SOUNDS COOL.

508
00:23:45,800 --> 00:23:49,166
IS THAT--I DON'T KNOW
IF THAT QUALIFIES AS COOL.

509

00:23:49,166 --> 00:23:50,666

BUT IT'S ACTUALLY--

510

00:23:50,666 --> 00:23:53,566

IT WAS THE FIRST

DNA VIRUS GENOME SEQUENCE

511

00:23:53,566 --> 00:23:57,066

BY SANGER AND COLLEAGUES

IN 1977

512

00:23:57,066 --> 00:24:00,766

WHEN HE DEVELOPED WHAT WE REFER

TO AS SANGER SEQUENCING.

513

00:24:00,766 --> 00:24:03,200

IT'S A SMALL GENOME

514

00:24:03,200 --> 00:24:05,966

OF A LITTLE BIT OVER 5,000

LETTERS OF GENETIC CODE.

515

00:24:05,966 --> 00:24:09,266

AND THE DNA IS INFECTIVE

OF E. COLI,

516

00:24:09,266 --> 00:24:11,200

AND THIS IS A VIRUS

517

00:24:11,200 --> 00:24:13,166

SPECIFIC FOR

THE BACTERIA E. COLI.

518

00:24:13,166 --> 00:24:15,733

SO BACTERIOPHAGE ARE VIRUSES

519

00:24:15,733 --> 00:24:18,633

THAT ONLY AFFECT BACTERIA.

520

00:24:18,633 --> 00:24:21,200

WE START WITH A GENETIC CODE
IN THE COMPUTER.

521

00:24:21,200 --> 00:24:24,700

AFTER RESEQUENCING TO MAKE SURE
WE HAD ACCURATE GENETIC CODE,

522

00:24:24,700 --> 00:24:27,633

AND WITH SOME NEW TOOLS
WE DEVELOPED,

523

00:24:27,633 --> 00:24:30,833

ONLY TOOK TWO WEEKS
TO SYNTHESIZE IT

524

00:24:30,833 --> 00:24:34,300

AND CORRECT THE ERRORS
IN THE GENETIC CODE.

525

00:24:34,300 --> 00:24:37,633

AND THEN WE FOUND WAYS
JUST TO INSERT THAT IN E. COLI.

526

00:24:37,633 --> 00:24:40,866

AND THIS WAS
THE FIRST EXPERIMENT.

527

00:24:40,866 --> 00:24:43,166

WHAT HAPPENS IS

528

00:24:43,166 --> 00:24:46,066

E. COLI STARTED TO READ
THE SYNTHETIC DNA,

529

00:24:46,066 --> 00:24:48,266

STARTED TO MAKE
THE PROTEINS.

530

00:24:48,266 --> 00:24:50,900
THE PROTEINS SELF-ASSEMBLED
TO FORM THE VIRUS.

531
00:24:50,900 --> 00:24:54,233
THE VIRUS ACCUMULATED
MILLIONS OF COPIES IN THE CELLS

532
00:24:54,233 --> 00:24:56,366
UNTIL THE CELLS BURST,

533
00:24:56,366 --> 00:24:59,233
AND THESE CLEAR SPOTS--
THIS IS A LOT OF E. COLI,

534
00:24:59,233 --> 00:25:01,566
SO EVERY PLACE YOU SEE
ONE OF THESE CIRCLES

535
00:25:01,566 --> 00:25:04,333
IS WHERE THE VIRUS HAS KILLED
LARGE NUMBERS OF CELLS,

536
00:25:04,333 --> 00:25:06,366
REINFECTED ADDITIONAL CELLS,

537
00:25:06,366 --> 00:25:08,133
AND KILLED MORE.

538
00:25:08,133 --> 00:25:09,900
SO WE CALL THIS A SITUATION

539
00:25:09,900 --> 00:25:13,833
WHERE THE SOFTWARE BUILDS
ITS OWN HARDWARE.

540
00:25:13,833 --> 00:25:16,000
OBVIOUSLY COMPUTER SCIENTISTS
WOULD LOVE IT

541

00:25:16,000 --> 00:25:18,366

IF YOU COULD JUST WRITE
SOME COMPUTER CODE

542

00:25:18,366 --> 00:25:21,933

AND GET A NEW COMPUTER
OUT OF IT.

543

00:25:21,933 --> 00:25:25,933

WE CAN AT LEAST GET INFECTIOUS
PARTICLES OUT OF IT

544

00:25:25,933 --> 00:25:28,333

WITH THIS EXPERIMENT.

545

00:25:28,333 --> 00:25:31,833

BUT OUR GOAL WAS TO MAKE
AN ENTIRE SELF-REPLICATING CELL,

546

00:25:31,833 --> 00:25:35,400

NOT A VIRUS THAT CAN JUST HIJACK
CELLULAR MACHINERY.

547

00:25:35,400 --> 00:25:38,866

BUT WE KNEW WE COULD NOW
ACCURATELY MAKE

548

00:25:38,866 --> 00:25:41,300

VIRAL-SIZE GENOMES.

549

00:25:41,300 --> 00:25:44,533

WE FIGURED IF WE COULD FIND
A WAY LINK THEM ALL TOGETHER

550

00:25:44,533 --> 00:25:47,333

WE MIGHT BE ABLE TO BUILD
A BACTERIAL CHROMOSOME,

551

00:25:47,333 --> 00:25:49,766

AND THAT'S WHAT
WE SET OUT TO DO.

552

00:25:49,766 --> 00:25:52,566

AND WE STARTED
WITH SOME VERY LABORIOUS

553

00:25:52,566 --> 00:25:55,000

MANUAL TECHNIQUES.

554

00:25:55,000 --> 00:25:58,833

WE DESIGNED THE GENOME
IN THESE CASSETTES

555

00:25:58,833 --> 00:26:01,966

AROUND 5,000 TO 7,000
BASE PAIRS.

556

00:26:01,966 --> 00:26:03,866

WE MADE EACH CASSETTE

557

00:26:03,866 --> 00:26:05,866

AND THEN WE STARTED
PUTTING THEM TOGETHER

558

00:26:05,866 --> 00:26:10,333

IN SOMETHING THAT LOOKS LIKE
A FINAL FOUR PLAYOFF.

559

00:26:10,333 --> 00:26:12,433

BUT AT EACH STAGE,

560

00:26:12,433 --> 00:26:15,900

TEAMS WERE WORKING ON DIFFERENT
ONES OF THESE.

561

00:26:15,900 --> 00:26:18,766

AFTER EACH PIECE WAS MADE,
THEY HAD TO CLONE AN E. COLI,

562

00:26:18,766 --> 00:26:20,466

GROW IT UP, SEQUENCE IT

563

00:26:20,466 --> 00:26:23,100

TO VALIDATE THAT WE HADN'T
INTRODUCED ERRORS,

564

00:26:23,100 --> 00:26:25,133

AND THEN ONCE
THAT WAS ALL DONE,

565

00:26:25,133 --> 00:26:27,733

WE WENT ON
TO THE NEXT STAGE.

566

00:26:27,733 --> 00:26:29,466

THE LARGEST PIECE OF DNA
AT THE TIME

567

00:26:29,466 --> 00:26:32,433

THAT IT WAS EVER SYNTHESIZED
WAS ONLY ABOUT 30KB.

568

00:26:32,433 --> 00:26:35,033

SO ONCE WE WERE AT
STAGE THREE,

569

00:26:35,033 --> 00:26:39,366

WE WERE WELL PAST
THE LARGEST PIECES.

570

00:26:39,366 --> 00:26:42,833

AND WHEN WE GOT
OVER 100,000 BASE PAIRS,

571

00:26:42,833 --> 00:26:45,966

CLONING E. COLI
BECAME COMPLICATED.

572

00:26:45,966 --> 00:26:49,333
THE E. COLI DIDN'T LIKE
THESE LARGE STRETCHES

573
00:26:49,333 --> 00:26:51,500
OF SYNTHETIC DNA,

574
00:26:51,500 --> 00:26:54,400
SOME OF WHICH CONTAINED
BACTERIAL GENES

575
00:26:54,400 --> 00:26:57,033
THAT COULD ACTUALLY BE TOXIC
TO E. COLI.

576
00:26:57,033 --> 00:26:59,500
SO WE STARTED LOOKING AROUND
FOR ANOTHER SYSTEM

577
00:26:59,500 --> 00:27:02,966
AND WE FOUND THAT MIRACLE BUG
SACCHAROMYCES CEREVISIAE,

578
00:27:02,966 --> 00:27:06,266
THAT GIVES US BEER
AND BREAD AND WINE--

579
00:27:06,266 --> 00:27:08,833
YOU KNOW, HUMIDITY
WOULD NOT HAVE SURVIVED

580
00:27:08,833 --> 00:27:11,500
WITHOUT THIS ORGANISM.

581
00:27:11,500 --> 00:27:14,933
AND IT ALSO TAKES UP
VERY LARGE PIECES OF DNA.

582
00:27:14,933 --> 00:27:17,066
IT CAN USE

HOMOLOGOUS RECOMBINATION.

583

00:27:17,066 --> 00:27:19,133
THAT'S WHERE YOU JUST HAVE
OVERLAPPING PIECES

584

00:27:19,133 --> 00:27:21,133
OF THE COMPLEMENTARY SEQUENCE

585

00:27:21,133 --> 00:27:22,866
AND THAT STITCHES THINGS
TOGETHER.

586

00:27:22,866 --> 00:27:24,866
SO THAT'S WHAT WE DID.

587

00:27:24,866 --> 00:27:29,266
WE PUT THESE QUARTER-GENOME
CHEMICALLY MADE PIECES

588

00:27:29,266 --> 00:27:31,233
WITH PROPER OVERLAPS

589

00:27:31,233 --> 00:27:34,600
INTO A YEAST
WITH A SIMPLE VECTOR

590

00:27:34,600 --> 00:27:37,033
THAT HAS A SYNTHETIC YEAST
CENTROMERE IN IT,

591

00:27:37,033 --> 00:27:40,866
AND YEAST IMMEDIATELY STITCHED
THESE PIECES TOGETHER.

592

00:27:40,866 --> 00:27:43,633
WE ISOLATED
AND SEQUENCED IT,

593

00:27:43,633 --> 00:27:45,966

AND THAT'S WHAT
WE REPORTED IN 2008

594

00:27:45,966 --> 00:27:50,000

AS THE--THE FIRST CHEMICALLY
MADE BACTERIAL GENOME.

595

00:27:51,733 --> 00:27:54,133

CHEMISTRY CONTINUED
TO IMPROVE--

596

00:27:54,133 --> 00:27:57,933

AND MANY OF YOU HERE KNOW
THIS YOUNG MAN, DAN GIBSON--

597

00:27:57,933 --> 00:28:00,600

HE STARTED AS A POSTDOC
IN THE LAB,

598

00:28:00,600 --> 00:28:04,833

AND HE TOOK WHAT WE WERE DOING
IN THESE LABORIOUS STEPS,

599

00:28:04,833 --> 00:28:06,866

AND HE
GREATLY SIMPLIFIED IT

600

00:28:06,866 --> 00:28:08,933

BY COMBINING THE ENZYMES

601

00:28:08,933 --> 00:28:12,233

AND THE OLIGONUCLEOTIDES

602

00:28:12,233 --> 00:28:15,600

IN A SINGLE REACTION
AT 50 DEGREES CENTIGRADE,

603

00:28:15,600 --> 00:28:17,966

BECAUSE AT THAT

TEMPERATURE,

604

00:28:17,966 --> 00:28:20,366

ONE OF THE KEY ENZYMES
GETS KILLED OFF

605

00:28:20,366 --> 00:28:23,133

BEFORE IT CHEWS BACK
TOO MUCH DNA.

606

00:28:23,133 --> 00:28:25,566

AND WE NAMED IT
THE GIBSON ASSEMBLY

607

00:28:25,566 --> 00:28:27,300

AFTER DAN GIBSON.

608

00:28:27,300 --> 00:28:29,700

AND HE CAME TO HAM SMITH
AND I--

609

00:28:29,700 --> 00:28:33,000

HAM SMITH IS NOW 82--

610

00:28:33,000 --> 00:28:37,000

AND HE SAID, "I DON'T KNOW
WHAT TOOK YOU OLD GUYS SO LONG."

611

00:28:37,000 --> 00:28:39,066

BUT THE KEY THING
ABOUT THIS,

612

00:28:39,066 --> 00:28:40,866

IT ALLOWS
FOR COMPLETE AUTOMATION,

613

00:28:40,866 --> 00:28:43,366

SO WE CAN GO FROM THE DIGITAL
CODE IN THE COMPUTER

614
00:28:43,366 --> 00:28:47,800
TO SYNTHETIC DNA
IN AN AUTOMATED PROCESS.

615
00:28:47,800 --> 00:28:50,133
SO THE CHEMISTRY
WAS GOING WELL.

616
00:28:50,133 --> 00:28:52,500
WE STARTED
A BIOLOGICAL TEAM

617
00:28:52,500 --> 00:28:56,033
TO WORK OUT HOW TO BOOT UP
THE CHROMOSOME.

618
00:28:56,033 --> 00:28:58,433
THAT WAS ACTUALLY
MUCH HARDER.

619
00:28:58,433 --> 00:29:01,900
WE HAD A FRENCH POSTDOC
AND JOHN GLASS AT THE INSTITUTE

620
00:29:01,900 --> 00:29:04,200
LEADING THE TEAM TO DO THIS.

621
00:29:04,200 --> 00:29:06,800
BECAUSE THIS PART OF THE BIOLOGY
IS ESSENTIAL

622
00:29:06,800 --> 00:29:09,000
TO SYNTHETIC GENOMICS,

623
00:29:09,000 --> 00:29:11,766
I'M GONNA WALK YOU THROUGH
WHAT WE DID,

624
00:29:11,766 --> 00:29:14,100

BECAUSE IT MAKES IT
SORT OF UNIVERSAL

625

00:29:14,100 --> 00:29:16,300

IN HOW WE THINK
ABOUT LIFE,

626

00:29:16,300 --> 00:29:18,566

AND HOPEFULLY HOW YOU WILL,
AS WELL.

627

00:29:18,566 --> 00:29:20,800

WE HAD TWO SPECIES
OF MYCOPLASMA--

628

00:29:20,800 --> 00:29:23,933

MYCOPLASMA MYCOIDES
AND CAPRICOLUM.

629

00:29:23,933 --> 00:29:26,733

THEY WERE ABOUT THE SAME
DISTANCE APART GENETICALLY

630

00:29:26,733 --> 00:29:28,500

AS WE ARE FROM MICE,

631

00:29:28,500 --> 00:29:30,966

SO ABOUT 10%.

632

00:29:30,966 --> 00:29:34,133

WE ISOLATED THE CHROMOSOME
FROM M. MYCOIDES.

633

00:29:34,133 --> 00:29:37,066

WE ADDED HARSH ENZYMES

634

00:29:37,066 --> 00:29:39,266

TO CHEW UP ALL THE PROTEINS,
'CAUSE WE NEEDED TO KNOW

635

00:29:39,266 --> 00:29:42,766

WHETHER WE COULD TRANSPLANT
NAKED DNA.

636

00:29:42,766 --> 00:29:44,633

WE ADDED A COUPLE CASSETTES
TO IT,

637

00:29:44,633 --> 00:29:46,566

ONE, SO WE COULD SELECT
FOR IT,

638

00:29:46,566 --> 00:29:48,933

AND ANOTHER, SO IT'D TURN
THE CELLS BRIGHT BLUE

639

00:29:48,933 --> 00:29:50,966

IF IT WAS ACTIVATED.

640

00:29:50,966 --> 00:29:52,533

AND WE DEVELOPED TECHNIQUES

641

00:29:52,533 --> 00:29:54,833

FOR TRANSPLANTING THAT

642

00:29:54,833 --> 00:29:57,200

INTO THE CAPRICOLUM CELL,

643

00:29:57,200 --> 00:29:59,000

AND THIS IS
WHAT TOOK SO LONG.

644

00:29:59,000 --> 00:30:02,200

BECAUSE YOU CAN'T PIPETTE
THESE CHROMOSOMES.

645

00:30:02,200 --> 00:30:04,200

LARGE PIECES OF DNA
ARE BRITTLE.

646

00:30:04,200 --> 00:30:05,700
IF YOU'RE PIPETTING THEM

647

00:30:05,700 --> 00:30:07,733
THEY FRACTIONATE
INTO SMALLER PIECES.

648

00:30:07,733 --> 00:30:11,566
SO WE ACTUALLY ISOLATE
THE CHROMOSOMES IN GEL BLOCKS.

649

00:30:11,566 --> 00:30:14,000
WE CAN DO ALL THE CHEMISTRY
IN THE GEL BLOCKS,

650

00:30:14,000 --> 00:30:16,766
AND THEN WE USE AN ENZYME
AT THE LAST SECOND

651

00:30:16,766 --> 00:30:18,733
TO DISSOLVE THE GEL

652

00:30:18,733 --> 00:30:22,333
AS WE USE ELECTRIC CURRENT
TO DRIVE IT INTO THE CELL.

653

00:30:22,333 --> 00:30:24,533
SO WE HAVE
THIS LITTLE VIDEO

654

00:30:24,533 --> 00:30:26,400
TO SHOW YOU
WHAT WE THINK HAPPENED.

655

00:30:26,400 --> 00:30:29,400
IT'S VERY SOPHISTICATED
FOR NASA.

656

00:30:29,400 --> 00:30:30,600
SO I HOPE YOU'RE READY.

657
00:30:30,600 --> 00:30:33,500
BUT WE INSERTED
THE NEW CHROMOSOME...

658
00:30:33,500 --> 00:30:37,200
[laughter]
INTO THE CELL.

659
00:30:37,200 --> 00:30:40,433
NOW WE HAVE THE CELL--
IT'S A PHENOTYPE--

660
00:30:40,433 --> 00:30:43,300
ALL THE CHARACTERISTICS
OF ONE SPECIES,

661
00:30:43,300 --> 00:30:46,266
BUT IT NOW HAS TWO SETS
OF GENETIC SOFTWARE.

662
00:30:46,266 --> 00:30:48,233
WHAT WE THINK HAPPENED

663
00:30:48,233 --> 00:30:50,566
IS THAT THE NEW CHROMOSOME
STARTED TO BE READ,

664
00:30:50,566 --> 00:30:53,533
IMMEDIATELY STARTED PRODUCING
ENZYMES AND PROTEINS.

665
00:30:53,533 --> 00:30:57,166
SOME OF THE EARLY PROTEINS
WERE THE RESTRICTION ENZYMES

666
00:30:57,166 --> 00:31:00,366
THAT CHEW UP DNA

THAT HAM SMITH DISCOVERED

667

00:31:00,366 --> 00:31:04,400

THAT LED TO HIS NOBEL PRIZE
IN 1978.

668

00:31:04,400 --> 00:31:07,433

THESE ENZYMES RECOGNIZED
THE CHROMOSOME IN THE CELL

669

00:31:07,433 --> 00:31:11,133

AS FOREIGN DNA
AND CHEWED IT UP.

670

00:31:11,133 --> 00:31:14,000

SO NOW WE HAVE
THE BODY OF ONE SPECIES

671

00:31:14,000 --> 00:31:15,866

AND THE GENETIC SOFTWARE
OF ANOTHER.

672

00:31:15,866 --> 00:31:17,633

SO WHAT HAPPENED?

673

00:31:17,633 --> 00:31:19,033

IN A SHORT PERIOD OF TIME,

674

00:31:19,033 --> 00:31:21,366

WE ENDED UP WITH
THESE BRIGHT BLUE CELLS.

675

00:31:21,366 --> 00:31:23,566

AND WHEN
WE INTERROGATED THEM,

676

00:31:23,566 --> 00:31:27,333

THERE WASN'T A SINGLE MOLECULE
OF THE ORIGINAL CELL LEFT.

677

00:31:27,333 --> 00:31:30,033

EVERYTHING IN THE CELL
DERIVED

678

00:31:30,033 --> 00:31:33,066

FROM THAT TRANSPLANTED
CHROMOSOME.

679

00:31:33,066 --> 00:31:36,000

SO THIS IS
SUCH A KEY PROCESS

680

00:31:36,000 --> 00:31:39,500

TO UNDERSTANDING
THE GENETIC CODE

681

00:31:39,500 --> 00:31:42,333

AND HOW IT WORKS,
BUT ALSO EVOLUTION.

682

00:31:42,333 --> 00:31:44,000

AND I THINK
IT HELPS TO PROVE

683

00:31:44,000 --> 00:31:47,033

THAT LIFE IS
A DNA SOFTWARE SYSTEM,

684

00:31:47,033 --> 00:31:49,433

AND IF YOU CHANGE
THE SOFTWARE,

685

00:31:49,433 --> 00:31:51,433

YOU CHANGE THE SPECIES.

686

00:31:51,433 --> 00:31:54,066

AND IF YOU LOOK BACK
AT EVOLUTION,

687

00:31:54,066 --> 00:31:58,500
WE SEE THIS HAPPENING OVER
AND OVER AND OVER AGAIN.

688
00:31:58,500 --> 00:32:00,433
IN FACT, EVOLUTION
DIDN'T TAKE PLACE

689
00:32:00,433 --> 00:32:03,633
IN JUST WHAT PEOPLE THINK
OF THESE POINT MUTATIONS

690
00:32:03,633 --> 00:32:06,333
AND YOU SELECT
FOR SOMETHING.

691
00:32:06,333 --> 00:32:09,100
WE FIND
IN THE BACTERIAL WORLD

692
00:32:09,100 --> 00:32:12,633
CELLS WITH TWO
AND THREE CHROMOSOMES,

693
00:32:12,633 --> 00:32:15,200
AND WHEN WE LOOK
AT THE CHROMOSOME STRUCTURE,

694
00:32:15,200 --> 00:32:19,766
THEY'RE CLEARLY DERIVED FROM
DIFFERENT EVOLUTIONARY ORIGINS.

695
00:32:19,766 --> 00:32:22,266
SO THESE EVENTS
OF XENOTRANSPLANTATION

696
00:32:22,266 --> 00:32:24,366
COULD BE
FROM A CELL FUSION,

697

00:32:24,366 --> 00:32:29,000
AND IF THERE WAS A MISMATCH
IN THE DNA RESTRICTION ENZYME

698
00:32:29,000 --> 00:32:31,500
SO DNA
DIDN'T GET DESTROYED,

699
00:32:31,500 --> 00:32:33,666
YOU COULD ADD,
IN ONE SINGLE STEP,

700
00:32:33,666 --> 00:32:37,766
A THOUSAND NEW TRAITS
TO THAT CELL.

701
00:32:37,766 --> 00:32:42,133
WE SEE THIS WITH THE DEVELOPMENT
OF THE ENTIRE PLANT WORLD

702
00:32:42,133 --> 00:32:45,266
WHERE A SMALL

703
00:32:45,266 --> 00:32:47,933
PROKARYOTIC
PHOTOSYNTHETIC CELL

704
00:32:47,933 --> 00:32:51,900
GOT INCORPORATED
INTO A EUKARYOTIC CELL,

705
00:32:51,900 --> 00:32:55,366
AND THAT GAVE US
THE PLANT WORLD.

706
00:32:55,366 --> 00:32:58,500
AND IN OUR OWN BODIES,
THE MITOCHONDRIAL GENOME

707
00:32:58,500 --> 00:33:01,100

WAS A BACTERIAL CELL

708

00:33:01,100 --> 00:33:04,400
THAT GOT INCORPORATED
INTO YOUR EUKARYOTIC CELL,

709

00:33:04,400 --> 00:33:06,766
AND THAT GIVES US
OUR ENERGY PLANT FORM

710

00:33:06,766 --> 00:33:09,633
FOR OXIDATIVE METABOLISM.

711

00:33:09,633 --> 00:33:11,900
BOTH IN THE CHLOROPLAST
IN PLANTS

712

00:33:11,900 --> 00:33:14,066
AND IN OUR MITOCHONDRIA,

713

00:33:14,066 --> 00:33:16,300
THEY HAVE SEPARATE GENOMES.

714

00:33:16,300 --> 00:33:19,433
THAT'S HOW ONE CAN TRACK
THE MATERNAL GENOME

715

00:33:19,433 --> 00:33:22,766
FROM THE PATERNAL GENOME
IN CELLS,

716

00:33:22,766 --> 00:33:27,033
BECAUSE THE MITOCHONDRIA
COMES ALONG WITH THE EGG

717

00:33:27,033 --> 00:33:30,700
AND IS ONLY PASSED DOWN
FROM MOTHER TO CHILD.

718

00:33:30,700 --> 00:33:34,266
AND SO WHEN YOU HEAR ABOUT
DNA BEING USED FOR FORENSICS,

719
00:33:34,266 --> 00:33:36,766
IT'S QUITE OFTEN
MITOCHONDRIAL DNA

720
00:33:36,766 --> 00:33:40,500
AND YOU CAN TRACK
THE MATERNAL LINEAGES.

721
00:33:40,500 --> 00:33:43,766
SO ALL THIS CHEMISTRY
WAS WORKING SO MUCH BETTER,

722
00:33:43,766 --> 00:33:46,700
WE DECIDED TO MAKE
A MUCH LARGER CHROMOSOME.

723
00:33:46,700 --> 00:33:50,166
AND WE'D BEEN DOING
ALL THIS WORK ON M. MYCOIDES

724
00:33:50,166 --> 00:33:53,166
SO WE DECIDED TO USE
THE GIBSON ASSEMBLY TOOLS

725
00:33:53,166 --> 00:33:58,100
TO MAKE THIS
1.1 MILLION BASE PAIR GENOME.

726
00:33:58,100 --> 00:34:00,766
WE STARTED WITH
1,000 BASE PAIR PIECES,

727
00:34:00,766 --> 00:34:02,600
PUT TEN OF THOSE TOGETHER

728
00:34:02,600 --> 00:34:04,433

TO GET 10KB PIECES.

729

00:34:04,433 --> 00:34:08,433

THEN WE PUT 10 OF THOSE TOGETHER
TO GET 100KB PIECES.

730

00:34:08,433 --> 00:34:11,166

THEN WE PUT 11 OF THOSE
INTO YEAST,

731

00:34:11,166 --> 00:34:14,133

AND IT ASSEMBLED
THE ENTIRE CHROMOSOME.

732

00:34:14,133 --> 00:34:17,733

WE DID THE TRANSPLANTATION,
AND IT DIDN'T WORK.

733

00:34:17,733 --> 00:34:20,366

SO THOSE OF YOU WHO WORK
IN THE SOFTWARE WORLD

734

00:34:20,366 --> 00:34:22,166

HAVE DEBUGGING SOFTWARE.

735

00:34:22,166 --> 00:34:24,166

WE HAD TO CREATE
A BIOLOGICAL VERSION

736

00:34:24,166 --> 00:34:26,233

OF THE DEBUGGING SOFTWARE

737

00:34:26,233 --> 00:34:28,100

TO FIND WHETHER IT WAS AN ERROR
IN OUR DESIGN

738

00:34:28,100 --> 00:34:30,266

AND OUR SYNTHESIS,
ET CETERA.

739

00:34:30,266 --> 00:34:33,333

AND WE BASICALLY SUBSTITUTED
THESE 100KB PIECES

740

00:34:33,333 --> 00:34:36,100

IN THE NATURAL CELL,

741

00:34:36,100 --> 00:34:40,066

AND WE FOUND TEN OF THEM WORKED
AND ONE DIDN'T.

742

00:34:40,066 --> 00:34:42,366

WE RESEQUENCED THE ONE,

743

00:34:42,366 --> 00:34:45,133

AND WE FOUND
A SINGLE BASE PAIR DELETION

744

00:34:45,133 --> 00:34:47,566

IN AN ESSENTIAL GENE,

745

00:34:47,566 --> 00:34:49,566

THAT IT CLEARLY MADE
ALL THE DIFFERENCE

746

00:34:49,566 --> 00:34:51,333

BETWEEN LIFE AND NO LIFE.

747

00:34:51,333 --> 00:34:53,466

WE CORRECTED
THAT ONE BASE PAIR,

748

00:34:53,466 --> 00:34:55,200

DID THE TRANSPLANTATION,

749

00:34:55,200 --> 00:34:59,566

AND WE GOT
THE FIRST SYNTHETIC CELL

750
00:34:59,566 --> 00:35:02,833
WE DEFINED
AS BEING POWERED COMPLETELY

751
00:35:02,833 --> 00:35:05,933
BY A CHEMICALLY MADE GENOME.

752
00:35:05,933 --> 00:35:08,500
SO THIS HAS NOW BEEN
FOUR YEARS

753
00:35:08,500 --> 00:35:11,600
SINCE WE REPORTED THIS
IN SCIENCE

754
00:35:11,600 --> 00:35:13,133
AND TO THE WORLD.

755
00:35:13,133 --> 00:35:15,600
AND MANY OF YOU
REMEMBER THE WAY

756
00:35:15,600 --> 00:35:19,100
THAT WE COULD PROVE IT WAS
TOTALLY SYNTHETIC DNA

757
00:35:19,100 --> 00:35:22,800
IS WE BUILT WATERMARKS
INTO THE GENETIC CODE.

758
00:35:22,800 --> 00:35:25,166
WE DEVELOPED A CODE
WHERE WE CAN WRITE

759
00:35:25,166 --> 00:35:27,766
THE ENTIRE ENGLISH LANGUAGE
WITH NUMBERS AND PUNCTUATION

760
00:35:27,766 --> 00:35:30,066

IN THE FOUR LETTERS OF DNA.

761

00:35:30,066 --> 00:35:34,166
AND WE INCLUDED THE NAMES
OF 46 SCIENTISTS,

762

00:35:34,166 --> 00:35:37,000
NAMES OF THE INSTITUTIONS,

763

00:35:37,000 --> 00:35:40,466
AND I CAME UP WITH THREE
QUOTATIONS FROM LITERATURE

764

00:35:40,466 --> 00:35:43,200
THAT I THOUGHT
MIGHT BE APPROPRIATE.

765

00:35:43,200 --> 00:35:45,500
THE FIRST
IS FROM JAMES JOYCE--

766

00:35:45,500 --> 00:35:48,033
"TO LIVE, TO ERR,
TO FALL, TO TRIUMPH,

767

00:35:48,033 --> 00:35:50,066
TO RE-CREATE LIFE
OUT OF LIFE."

768

00:35:50,066 --> 00:35:52,433
THAT SEEMED TO FIT
WHAT WE WERE DOING.

769

00:35:52,433 --> 00:35:55,166
THE SECOND SOME OF YOU
PROBABLY RECOGNIZE,

770

00:35:55,166 --> 00:35:58,600
IT'S FROM OPPENHEIMER'S
BIOGRAPHY "AMERICAN PROMETHEUS,"

771

00:35:58,600 --> 00:36:01,100

TOLD TO HIM

BY AN EARLY TEACHER--

772

00:36:01,100 --> 00:36:04,033

"SEE THINGS NOT AS THEY ARE,

BUT AS THEY MIGHT BE."

773

00:36:04,033 --> 00:36:06,700

AND THE THIRD

FROM RICHARD FEYNMAN--

774

00:36:06,700 --> 00:36:09,533

"WHAT I CANNOT BUILD,

I CANNOT UNDERSTAND."

775

00:36:11,366 --> 00:36:15,300

ONCE--AND ALSO,

THERE'S A URL BUILT INTO THIS,

776

00:36:15,300 --> 00:36:18,200

AND WE CREATED SORT OF A CONTEST

FOR PEOPLE TO DECODE THIS.

777

00:36:18,200 --> 00:36:21,300

THEY SENT AN E-MAIL

TO THE SPECIES,

778

00:36:21,300 --> 00:36:23,233

AND ONCE A NUMBER OF PEOPLE

DECODED IT,

779

00:36:23,233 --> 00:36:25,466

WE MADE IT AVAILABLE.

780

00:36:25,466 --> 00:36:27,500

AND ONE OF THE FIRST RESPONSES

WE GOT

781
00:36:27,500 --> 00:36:30,200
WAS A LETTER FROM
JAMES JOYCE ESTATE ATTORNEY...

782
00:36:30,200 --> 00:36:32,466
[laughter]

783
00:36:32,466 --> 00:36:36,000
ASKING US IF WE HAD
COPYRIGHT PERMISSION.

784
00:36:36,000 --> 00:36:39,433
BUT UNDER AMERICAN LAW,
YOU CAN USE UP TO A PARAGRAPH

785
00:36:39,433 --> 00:36:43,100
AS LONG AS
IT'S WITH ATTRIBUTION.

786
00:36:43,100 --> 00:36:46,000
AND THEN WE STARTED GETTING
E-MAILS FROM A CALTECH SCIENTIST

787
00:36:46,000 --> 00:36:49,033
SAYING WE HAD MISQUOTED
RICHARD FEYNMAN.

788
00:36:49,033 --> 00:36:51,833
JAMES JOYCE WAS DEAD
AND SO WAS RICHARD FEYNMAN

789
00:36:51,833 --> 00:36:53,700
AT THE TIME.

790
00:36:53,700 --> 00:36:56,466
I THINK THEY STILL ARE, BUT...
[laughter]

791
00:36:56,466 --> 00:36:59,166

IF YOU GO ON THE INTERNET,
THIS IS THE MAIN QUOTE

792

00:36:59,166 --> 00:37:01,266

THAT YOU FIND
DOING GOOGLE SEARCHES.

793

00:37:01,266 --> 00:37:05,033

AND IT TURNS OUT HIS BIOGRAPHER
MADE AN ERROR

794

00:37:05,033 --> 00:37:07,700

IN WRITING ABOUT THIS.

795

00:37:07,700 --> 00:37:10,433

AND HERE'S THE--AS PROOF, THEY
SENT A PHOTO OF THE CALTECH--

796

00:37:10,433 --> 00:37:13,733

A BLACKBOARD--
SO THE ORIGINAL QUOTATION IS--

797

00:37:13,733 --> 00:37:16,566

"WHAT I CANNOT CREATE,
I DO NOT UNDERSTAND."

798

00:37:16,566 --> 00:37:19,233

SO WE'VE GONE BACK
AND CHANGED THE GENETIC CODE

799

00:37:19,233 --> 00:37:22,533

SO FEYNMAN
WILL REST PEACEFULLY.

800

00:37:22,533 --> 00:37:24,366

[laughter]

801

00:37:24,366 --> 00:37:26,366

SO WHAT'S HAPPENED
IN THE LAST FOUR YEARS?

802

00:37:26,366 --> 00:37:30,166

WE'VE BEEN LEARNING HOW
TO DESIGN A CELL FROM SCRATCH.

803

00:37:30,166 --> 00:37:34,266

AND YOU'D THINK THIS WOULD BE
REALLY STRAIGHTFORWARD TO DO.

804

00:37:34,266 --> 00:37:36,133

THERE'S NOT--

805

00:37:36,133 --> 00:37:38,300

THERE'S ONLY ABOUT 900 GENES
IN THIS GENOME,

806

00:37:38,300 --> 00:37:41,633

AND YOU'D THINK THAT YOU COULD
KNOCK THEM OUT ONE AT A TIME

807

00:37:41,633 --> 00:37:43,700

AND FIND OUT WHICH ONES
WERE ESSENTIAL FOR LIFE

808

00:37:43,700 --> 00:37:46,266

AND WHICH ONES AREN'T,

809

00:37:46,266 --> 00:37:49,533

AND WE'VE BEEN DOING THAT
FOR A LONG PERIOD OF TIME.

810

00:37:49,533 --> 00:37:51,733

THIS IS--

811

00:37:51,733 --> 00:37:55,333

WHEN YOU CONVERT THE GENOME
INTO GENES

812

00:37:55,333 --> 00:37:57,733

IN M. MYCOIDES,
THIS IS WHAT IT LOOKS LIKE,

813

00:37:57,733 --> 00:38:00,500
AND IT'S TRYING TO WORK OUT
WHICH OF THOSE GENES

814

00:38:00,500 --> 00:38:02,166
ARE ESSENTIAL FOR LIFE

815

00:38:02,166 --> 00:38:04,633
IN THE CONTEXT
OF THE OTHERS.

816

00:38:04,633 --> 00:38:07,166
THE ANALOGY WE USE

817

00:38:07,166 --> 00:38:09,766
IS WITH A SEVEN TRIPLE SEVEN.

818

00:38:09,766 --> 00:38:13,066
IF YOU'RE DOING PARTS KNOCKOUT
TO FIND OUT WHAT'S ESSENTIAL,

819

00:38:13,066 --> 00:38:15,900
YOU CAN REMOVE ONE ENGINE

820

00:38:15,900 --> 00:38:20,133
AND THE AIRPLANE WILL STILL FLY
AND LAND SAFELY.

821

00:38:20,133 --> 00:38:23,133
IF YOU REMOVE THEM BOTH,
IT WON'T.

822

00:38:23,133 --> 00:38:26,033
AND THAT'S SORT OF WHAT HAPPENS
WITH BIOLOGY.

823

00:38:26,033 --> 00:38:28,200

THERE'S REDUNDANCY
BUILT IN,

824

00:38:28,200 --> 00:38:30,600

BUT THE REDUNDANCY
IS NOT OBVIOUS.

825

00:38:30,600 --> 00:38:32,400

IT'S NOT THE SAME STRUCTURE.

826

00:38:32,400 --> 00:38:34,766

IT'S NOT THE SAME
PROTEIN FAMILIES.

827

00:38:34,766 --> 00:38:39,400

AND WHEN WE GET DOWN TO
SORT OF OUR MINIMAL GENOME,

828

00:38:39,400 --> 00:38:43,766

ABOUT 1/4 OF THE GENES
IN THIS CELL

829

00:38:43,766 --> 00:38:46,000

ARE OF UNKNOWN FUNCTION.

830

00:38:46,000 --> 00:38:49,666

THE ONLY THING WE KNOW IS
THAT IF YOU REMOVE THAT GENE

831

00:38:49,666 --> 00:38:53,033

YOU CAN'T GET A LIVING
SELF-REPLICATING CELL.

832

00:38:53,033 --> 00:38:56,300

MY UNCLE IS 91.

833

00:38:56,300 --> 00:39:01,400

HE DESIGNED THE BOEING 757
AND 767.

834

00:39:01,400 --> 00:39:05,700

AND I SAID, "IMAGINE IF YOU WERE
DESIGNING THESE AIRPLANES

835

00:39:05,700 --> 00:39:08,566

AND YOU DIDN'T KNOW
WHAT 20% OF THE PARTS DID."

836

00:39:08,566 --> 00:39:10,633

HE SAID, "WHAT MAKES YOU THINK
WE KNEW?"

837

00:39:10,633 --> 00:39:12,366

[laughter]

838

00:39:12,366 --> 00:39:14,466

IN FACT, THE AIRLINE--

839

00:39:14,466 --> 00:39:16,533

THE AVIATION HISTORY

840

00:39:16,533 --> 00:39:19,166

IS HAVING FAILURES
AND THEN GOING BACK

841

00:39:19,166 --> 00:39:22,100

AND DISSECTING WHAT THE FAILURE
WAS AND CORRECTING IT NEXT TIME.

842

00:39:22,100 --> 00:39:23,733

IT'S KIND OF AN EXPENSIVE WAY
TO GO,

843

00:39:23,733 --> 00:39:26,533

BUT THAT'S WHAT WE'VE BEEN DOING
WITH THE GENOME.

844

00:39:26,533 --> 00:39:30,000

BUT WHEN 1/4 OF YOUR PARTS
ARE OF UNKNOWN FUNCTION,

845

00:39:30,000 --> 00:39:34,166
IT'S HARD TO WORK OUT AND DO
DESIGN ON FIRST PRINCIPLES,

846

00:39:34,166 --> 00:39:38,200
BUT WE'RE VERY CLOSE NOW
ON THIS FIRST CELL

847

00:39:38,200 --> 00:39:40,466
DESIGNED COMPLETELY
IN THE COMPUTER.

848

00:39:40,466 --> 00:39:42,333
WE THINK IT'S GONNA WORK,

849

00:39:42,333 --> 00:39:45,233
AND WE'LL FIND OUT
IN JUST A FEW WEEKS.

850

00:39:45,233 --> 00:39:47,200
THE NEXT STAGE
WE'VE BEEN WORKING ON

851

00:39:47,200 --> 00:39:49,533
IS TO DEFRAG THE GENOME.

852

00:39:49,533 --> 00:39:51,733
YOU KNOW,
EVOLUTION IS MESSY.

853

00:39:51,733 --> 00:39:54,400
THERE'S ALL KINDS OF
REARRANGEMENTS.

854

00:39:54,400 --> 00:39:57,700
DNA CAN BE CODED
ON EITHER STRAND.

855

00:39:57,700 --> 00:39:59,600

IT TURNS OUT,
DIRECTIONALITY IS IMPORTANT

856

00:39:59,600 --> 00:40:01,300

FROM THE ORIGIN
OF REPLICATION.

857

00:40:01,300 --> 00:40:03,266

SO THERE'S A HIGHER ORDER,

858

00:40:03,266 --> 00:40:05,166

BUT IF WE'RE GONNA
DO DESIGN,

859

00:40:05,166 --> 00:40:07,233

WE WANT TO HAVE CASSETTES
BY FUNCTION

860

00:40:07,233 --> 00:40:08,700

THAT WE CAN SORT OUT.

861

00:40:08,700 --> 00:40:12,300

SO WE'VE BEEN DOING
THIS DEFRAGGING PROCESS.

862

00:40:12,300 --> 00:40:14,366

AGAIN, IT'S DIFFICULT TO DO

863

00:40:14,366 --> 00:40:18,133

WITH 1/4 OF THE GENES
OF UNKNOWN FUNCTION.

864

00:40:18,133 --> 00:40:20,266

SO THAT CREATES CHALLENGES.

865

00:40:20,266 --> 00:40:22,533

WE'RE USING THIS TECHNOLOGY

IN OTHER AREAS.

866

00:40:22,533 --> 00:40:25,500

WE RECENTLY ANNOUNCED THIS
PROGRAM WITH UNITED THERAPEUTICS

867

00:40:25,500 --> 00:40:29,566

WITH OUR GOAL TO HUMANIZE
THE PIG GENOME

868

00:40:29,566 --> 00:40:33,600

TO MAKE PIG ORGANS
FOR TRANSPLANTATION.

869

00:40:33,600 --> 00:40:36,466

THERE'S ABOUT
1/4 OF A MILLION DEATHS

870

00:40:36,466 --> 00:40:40,466

JUST FROM PEOPLE
THAT NEED LUNG TRANSPLANTS

871

00:40:40,466 --> 00:40:44,033

AND CAN'T GET THEM.

872

00:40:44,033 --> 00:40:45,833

MOST OF YOU KNOW
THIS HAS BEEN DONE

873

00:40:45,833 --> 00:40:48,300

WITH HUMANIZING
MONOCLONAL ANTIBODIES.

874

00:40:48,300 --> 00:40:51,633

SO YOU CAN MAKE
MONOCLONAL ANTIBODIES IN MICE,

875

00:40:51,633 --> 00:40:53,766

BUT THERE ARE ACTUAL HUMAN
MONOCLONAL ANTIBODIES,

876

00:40:53,766 --> 00:40:56,566

AND THAT'S WHERE A LOT OF THE
HUMAN THERAPEUTICS COME FROM.

877

00:40:56,566 --> 00:41:00,666

AND WE'RE NOW UNDERTAKING

878

00:41:00,666 --> 00:41:03,333

TO REWRITE THE PIG GENOME.

879

00:41:03,333 --> 00:41:07,166

AND WE'RE STARTING--

FIRST, WE HAVE TO GENERATE

880

00:41:07,166 --> 00:41:10,666

A SUPERACCURATE VERSION
OF THE PIG GENOME.

881

00:41:10,666 --> 00:41:13,733

SO WE'RE DOING THIS

WITH SOME NEW TECHNOLOGY

882

00:41:13,733 --> 00:41:17,233

USING A COMBINATION OF PACBIO
AND ILLUMINA SEQUENCING.

883

00:41:17,233 --> 00:41:19,600

BECAUSE THERE'S

A HUGE DIFFERENCE

884

00:41:19,600 --> 00:41:21,633

BETWEEN READING

THE GENETIC CODE

885

00:41:21,633 --> 00:41:23,566

AND WRITING

THE GENETIC CODE.

886

00:41:23,566 --> 00:41:27,333
YOU CAN INFER,
EVEN AS MUCH AS 10% ERRORS,

887
00:41:27,333 --> 00:41:29,733
WHAT THE GENOME IS.

888
00:41:29,733 --> 00:41:32,366
IF YOU'RE WRITING
THE GENETIC CODE,

889
00:41:32,366 --> 00:41:35,533
AS I SHOWED WITH MYCOIDES
SYNTHETIC GENOME,

890
00:41:35,533 --> 00:41:37,233
ONE BASE PAIR BEING WRONG

891
00:41:37,233 --> 00:41:39,900
CAN MAKE THE DIFFERENCE
BETWEEN LIFE AND NO LIFE.

892
00:41:39,900 --> 00:41:43,500
SO THE ACCURACY
WHEN YOU'RE RE-CREATING LIFE

893
00:41:43,500 --> 00:41:46,766
HAS TO BE
SUBSTANTIALLY HIGHER.

894
00:41:46,766 --> 00:41:49,933
WE'LL WORK ON DESIGNING
WHICH PARTS OF THE GENOME

895
00:41:49,933 --> 00:41:52,733
WE HAVE TO CHANGE
TO HUMANIZE.

896
00:41:52,733 --> 00:41:54,733
AND THE GOAL

AT SYNTHETIC GENOMICS

897

00:41:54,733 --> 00:41:58,033

IS TO ACTUALLY DESIGN AND BUILD
A NEW CELL.

898

00:41:58,033 --> 00:42:01,266

WE'LL GIVE THAT CELL
TO UNITED THERAPEUTICS.

899

00:42:01,266 --> 00:42:03,833

THEY'RE GONNA, INSTEAD OF DOING
GENOME TRANSPLANTATION

900

00:42:03,833 --> 00:42:05,566

WITH EUKARYOTIC CELLS,

901

00:42:05,566 --> 00:42:07,666

YOU CAN JUST TRANSPLANT
THE NUCLEUS.

902

00:42:07,666 --> 00:42:09,833

SO THEY'RE GONNA TAKE
OUR ENGINEERED CELL,

903

00:42:09,833 --> 00:42:12,500

TRANSPLANT THAT,
GENERATE PIG EMBRYOS,

904

00:42:12,500 --> 00:42:15,633

AND GENERATE PIGS
THAT THEN,

905

00:42:15,633 --> 00:42:17,700

AS THE PIGS ARE OLDER,

906

00:42:17,700 --> 00:42:20,866

THEY'LL USE THOSE ORGANS
FOR TRANSPLANTATION.

907
00:42:20,866 --> 00:42:22,466
THIS HAS ACTUALLY BEEN EFFECTIVE

908
00:42:22,466 --> 00:42:25,000
JUST CHANGING FIVE GENES.

909
00:42:25,000 --> 00:42:28,433
THEY'VE GOTTEN TRANSPLANTS
TO HAVE LASTED OVER A YEAR

910
00:42:28,433 --> 00:42:30,400
IN BABOONS.

911
00:42:30,400 --> 00:42:32,433
BUT TO GET IT
SO IT'S REALLY EFFECTIVE

912
00:42:32,433 --> 00:42:36,533
FOR HUMAN TRANSPLANTATION
ON A ROUTINE BASIS,

913
00:42:36,533 --> 00:42:39,266
WE HAVE TO MAKE
A SUBSTANTIAL NUMBER OF CHANGES.

914
00:42:39,266 --> 00:42:41,566
BUT THE TOOLS
ARE NOW READY

915
00:42:41,566 --> 00:42:44,566
TO START REWRITING
THE GENETIC CODE.

916
00:42:44,566 --> 00:42:48,100
IT'S A--PETE WARNED ME
AHEAD OF TIME, HE HAD TO LEAVE,

917
00:42:48,100 --> 00:42:51,366
BUT THIS IS THE PART HE LIKES

IN TERMS OF THE INTER-CONVERSION

918

00:42:51,366 --> 00:42:54,533
OF DNA AND THE COMPUTER.

919

00:42:54,533 --> 00:42:58,166
AND WE TESTED IT IN A PROJECT
WITH A TEAM HERE AT NASA

920

00:42:58,166 --> 00:43:01,700
OUT IN THE MOJAVE DESERT,

921

00:43:01,700 --> 00:43:04,266
TESTING OUR--
OUR SENDING UNIT

922

00:43:04,266 --> 00:43:07,000
FOR THE BIOLOGICAL TRANSPORTER.

923

00:43:07,000 --> 00:43:11,433
WE WENT OUT TO THE NASA
TEST SITE IN THE MOJAVE DESERT,

924

00:43:11,433 --> 00:43:14,500
TOOK SAMPLES OF SOIL.

925

00:43:14,500 --> 00:43:17,700
A ROBOT WEARS
THESE NICE GLOVES.

926

00:43:17,700 --> 00:43:19,866
[laughter]
YOU KNOW?

927

00:43:19,866 --> 00:43:22,400
BUT IT WAS VERY EFFECTIVE.

928

00:43:22,400 --> 00:43:24,933
AND THEN WE SEQUENCED THEM

929

00:43:24,933 --> 00:43:26,833

IN OUR LAB BUS
RIGHT ON-SITE,

930

00:43:26,833 --> 00:43:29,966

SO THAT--THAT'S PETE UP THERE
RUNNING ONE OF THE MACHINES

931

00:43:29,966 --> 00:43:31,500

WHILE HE WAS THERE.

932

00:43:31,500 --> 00:43:36,766

SO IT GENERATED TREMENDOUS
DIVERSITY OF ORGANISMS.

933

00:43:36,766 --> 00:43:38,733

IT WASN'T
JUST A SIMPLE COLONY,

934

00:43:38,733 --> 00:43:41,466

EVEN THOUGH IT LOOKED LIKE THAT
BIOLOGICALLY.

935

00:43:41,466 --> 00:43:43,833

WE JUST SEND IT UP
TO THE CLOUD,

936

00:43:43,833 --> 00:43:45,666

DOWNLOADED THAT
AT THE INSTITUTE,

937

00:43:45,666 --> 00:43:47,866

AND DID ALL THE ANALYSIS.

938

00:43:47,866 --> 00:43:50,033

SO THAT'S
THE SENDING UNIT.

939

00:43:50,033 --> 00:43:54,600
THE RECEIVING UNIT IS BASED ON
TAKING IN A DIGITAL SIGNAL

940
00:43:54,600 --> 00:43:57,300
AND CONVERTING IT BACK
INTO BIOLOGY.

941
00:43:57,300 --> 00:43:59,966
SO WITH HELP FROM DARPA,
WE ACTUALLY BUILT A PROTOTYPE

942
00:43:59,966 --> 00:44:02,400
OF THIS MACHINE.

943
00:44:02,400 --> 00:44:05,200
AND IT'S BEEN
THOROUGHLY TESTED NOW

944
00:44:05,200 --> 00:44:06,933
FOR FUNCTIONALITY

945
00:44:06,933 --> 00:44:10,266
OF BEING ABLE TO SEND
A DIGITAL SIGNAL TO IT.

946
00:44:10,266 --> 00:44:13,133
AT FIRST, WE HAD TO DO DNA
ASSEMBLY

947
00:44:13,133 --> 00:44:17,266
AND ACCURATELY PRODUCE
LARGE PIECES OF DNA.

948
00:44:17,266 --> 00:44:20,400
THEN WE HAD TO SHOW THAT IT
COULD ACTUALLY MAKE PROTEINS.

949
00:44:22,033 --> 00:44:25,166
AND WE HAD TO MAKE RNA,

950
00:44:25,166 --> 00:44:29,366
AND THEN WE ACTUALLY MADE THE--
A FLU VIRUS

951
00:44:29,366 --> 00:44:32,700
AND GOT IT
SO THE NEW VACCINE

952
00:44:32,700 --> 00:44:34,833
COULD BE RESCUED FROM THAT,

953
00:44:34,833 --> 00:44:37,666
AND THE FINAL STAGE IS JUST
SENDING A DIGITAL SIGNAL.

954
00:44:37,666 --> 00:44:40,166
IT PRODUCED PHIX174

955
00:44:40,166 --> 00:44:43,266
BACK TO OUR ORIGINS OF THE VERY
FIRST EXPERIMENT WE DID,

956
00:44:43,266 --> 00:44:46,833
WHICH WAS THEN ABLE
TO INFECT E. COLI

957
00:44:46,833 --> 00:44:48,866
AND KILL THE BACTERIA.

958
00:44:48,866 --> 00:44:51,400
SO WE'RE ABLE
TO ACTUALLY SEND BIOLOGY

959
00:44:51,400 --> 00:44:53,066
THROUGH THE INTERNET.

960
00:44:53,066 --> 00:44:56,733
WE CAN MAKE DNA, RNA,

PROTEINS, AND PHAGE

961

00:44:56,733 --> 00:45:01,533

AND SIMPLE

SELF-REPLICATING CELLS.

962

00:45:01,533 --> 00:45:04,333

THE FUTURE WE'VE--

963

00:45:04,333 --> 00:45:07,366

TO SEND FAR MORE

THROUGH THAT.

964

00:45:07,366 --> 00:45:10,666

SYNTHETIC GENOMICS

HAS THE FIRST

965

00:45:10,666 --> 00:45:13,066

GN--DNA ASSEMBLY ROBOT.

966

00:45:13,066 --> 00:45:16,366

THAT'S GONNA BE ON THE MARKET

LATER THIS YEAR.

967

00:45:16,366 --> 00:45:19,733

THIS IS NOT THE COMPLETELY

AUTOMATED VERSION.

968

00:45:19,733 --> 00:45:22,033

THIS TAKES INPUT

OF OLIGONUCLEOTIDES

969

00:45:22,033 --> 00:45:24,133

AND IT AUTOMATICALLY

ASSEMBLES IT

970

00:45:24,133 --> 00:45:26,300

INTO LARGE PIECES OF DNA.

971

00:45:26,300 --> 00:45:30,333
THE NEXT VERSIONS WILL ALSO HAVE
THE SYNTHETIC CAPABILITY.

972
00:45:30,333 --> 00:45:32,666
BUT JUST THINK ABOUT
SOME OF THE PROBLEMS

973
00:45:32,666 --> 00:45:34,400
YOU GUYS ARE FACING

974
00:45:34,400 --> 00:45:36,566
OF TRYING TO GET SAMPLES,

975
00:45:36,566 --> 00:45:40,200
FOR EXAMPLE,
BACK FROM MARS.

976
00:45:40,200 --> 00:45:42,966
USING
LIFE AT THE SPEED OF LIGHT

977
00:45:42,966 --> 00:45:46,133
AND SENDING
DIGITAL DNA INFORMATION

978
00:45:46,133 --> 00:45:48,400
WHEN EARTH AND MARS
ARE AT THEIR CLOSEST,

979
00:45:48,400 --> 00:45:50,166
IT COULD BE AS LITTLE
AS 4.3 MINUTES

980
00:45:50,166 --> 00:45:53,933
TO GET A SAMPLE BACK HERE.

981
00:45:53,933 --> 00:45:57,300
WE COULD SEND IT
TO A SPACE SUIT LAB

982

00:45:57,300 --> 00:46:00,900

INSTEAD OF SPLASHING IT DOWN
IN THE MIDDLE OF THE OCEAN.

983

00:46:00,900 --> 00:46:02,600

AS YOU--
MANY OF YOU ARE AWARE,

984

00:46:02,600 --> 00:46:05,933

SAMPLE RETURN IS
FRAUGHT WITH POLITICAL ISSUES

985

00:46:05,933 --> 00:46:09,233

ALTHOUGH, YOU KNOW,

986

00:46:09,233 --> 00:46:12,066

WHEN THE ASTRONAUTS
FIRST CAME BACK

987

00:46:12,066 --> 00:46:14,366

FROM MAR--FROM THE MOON

988

00:46:14,366 --> 00:46:17,600

AND SPLASHED DOWN
INTO THE OCEAN

989

00:46:17,600 --> 00:46:21,900

AND THEN PARADED AROUND THE DECK
OF AN AIRCRAFT CARRIER

990

00:46:21,900 --> 00:46:24,700

AND THEN GOT INTO
THE DECONTAMINATION UNITS

991

00:46:24,700 --> 00:46:26,833

FOR TWO WEEKS,

992

00:46:26,833 --> 00:46:29,400

OBVIOUSLY,
NASA NEEDS SOME PEOPLE

993
00:46:29,400 --> 00:46:31,533
THAT HAVE WORKED
IN STERILE ENVIRONMENTS

994
00:46:31,533 --> 00:46:33,233
AND SURGICAL UNITS

995
00:46:33,233 --> 00:46:36,400
TO KNOW WHAT YOU CAN CONTAMINATE
AND HOW YOU CONTAIN IT, SO...

996
00:46:36,400 --> 00:46:39,033
BUT WE COULD--
WE COULD SEND IT DIGITALLY

997
00:46:39,033 --> 00:46:41,600
RIGHT BACK
TO A SPACE SUIT LAB

998
00:46:41,600 --> 00:46:44,700
AND REBUILD THE--
THE ALIEN LIFE THERE,

999
00:46:44,700 --> 00:46:46,900
IF ONE SO WANTED TO.

1000
00:46:46,900 --> 00:46:48,400
WE'VE BEEN TALKING ABOUT
EXPERIMENTS,

1001
00:46:48,400 --> 00:46:52,833
SENDING BIOLOGY DIGITALLY
TO AND FROM THE SPACE STATION

1002
00:46:52,833 --> 00:46:56,500
AS PERHAPS
ONE OF THE NEXT STEPS.

1003

00:46:56,500 --> 00:47:00,333

AND THIS HAS IMPLICATIONS
IN WHAT WE CAN DO WITH MEDICINE.

1004

00:47:02,166 --> 00:47:05,266

WE'VE BEEN WORKING ON VACCINES
FOR A LONG TIME.

1005

00:47:05,266 --> 00:47:07,200

WE WERE WORKING
WITH NOVARTIS,

1006

00:47:07,200 --> 00:47:10,266

AND OUR FIRST
GENOME-BASED VACCINE

1007

00:47:10,266 --> 00:47:12,000

JUST GOT APPROVED IN EUROPE

1008

00:47:12,000 --> 00:47:14,666

AND WILL BE APPROVED,
WE THINK, IN THE U.S.

1009

00:47:14,666 --> 00:47:18,300

IT'S AGAINST MENINGITIS B.

1010

00:47:18,300 --> 00:47:20,100

THOSE OF YOU WHO HAVE--

1011

00:47:20,100 --> 00:47:21,866

YOU'RE EITHER
COLLEGE-AGE KIDS

1012

00:47:21,866 --> 00:47:24,333

OR YOU HAVE KIDS THAT AGE,

1013

00:47:24,333 --> 00:47:26,133

SHOULD DEFINITELY

PAY ATTENTION TO THIS

1014

00:47:26,133 --> 00:47:28,633

WITH THE OUTBREAKS IN PRINCETON

1015

00:47:28,633 --> 00:47:31,300

AND UC SANTA BARBARA

1016

00:47:31,300 --> 00:47:34,200

AND ALSO SOME CASES
IN RIVERSIDE.

1017

00:47:34,200 --> 00:47:37,200

BASICALLY,
THE CDC AND THE FDA

1018

00:47:37,200 --> 00:47:40,133

ARRANGED FOR IMMEDIATE USE

1019

00:47:40,133 --> 00:47:42,733

OF THE NEW
MENINGITIS B VACCINE

1020

00:47:42,733 --> 00:47:45,033

TO STOP THOSE--

1021

00:47:45,033 --> 00:47:48,300

STOP THOSE POTENTIALLY--

1022

00:47:48,300 --> 00:47:50,366

INFECTIONS FROM SPREADING
FURTHER.

1023

00:47:50,366 --> 00:47:53,733

BUT MENINGITIS IS
ONE OF THOSE DISEASES

1024

00:47:53,733 --> 00:47:56,266

THAT'S TOTALLY PREVENTABLE

WITH A VACCINE,

1025

00:47:56,266 --> 00:47:58,400

BUT BY THE TIME

YOU CAN DIAGNOSE IT,

1026

00:47:58,400 --> 00:48:00,366

IT'S TOO LATE FOR PEOPLE.

1027

00:48:00,366 --> 00:48:04,333

SO IF YOU'RE THAT AGE

OR HAVE KIDS THAT AGE,

1028

00:48:04,333 --> 00:48:06,266

I HIGHLY RECOMMEND IT,

1029

00:48:06,266 --> 00:48:09,400

AND IT SHOULD BE AVAILABLE SOON

IN THE U.S.

1030

00:48:09,400 --> 00:48:12,533

INFLUENZA IS A VACCINE

THAT HAS TO BE MADE ANNUALLY.

1031

00:48:12,533 --> 00:48:15,166

THE BIG FEAR,

GOING BACK TO 1918,

1032

00:48:15,166 --> 00:48:18,466

WHERE ABOUT 3%

OF THE WORLD'S POPULATION

1033

00:48:18,466 --> 00:48:22,300

WERE KILLED

FROM THE 1918 FLU VIRUS.

1034

00:48:22,300 --> 00:48:24,966

IT TURNED OUT

1035

00:48:24,966 --> 00:48:27,266
SOME PEOPLE BURIED
IN THE PERMAFROST

1036
00:48:27,266 --> 00:48:30,133
AND SOME SAMPLES
IN ARMY FREEZERS

1037
00:48:30,133 --> 00:48:33,800
IN--IN WASHINGTON, D.C.,

1038
00:48:33,800 --> 00:48:37,000
THE TISSUE STILL CONTAINED
LIVE VIRUS.

1039
00:48:37,000 --> 00:48:39,133
IT WAS ISOLATED
AND SEQUENCED

1040
00:48:39,133 --> 00:48:42,233
AND THE CDC
REPRODUCED THE VIRUS

1041
00:48:42,233 --> 00:48:46,166
SO WE COULD UNDERSTAND
MORE ABOUT IT,

1042
00:48:46,166 --> 00:48:50,233
AND SO WE CAN RECOGNIZE
DANGEROUS COMPONENTS OF THIS.

1043
00:48:50,233 --> 00:48:54,933
AND THIS HAPPENED IN REAL TIME
WITH H7N9.

1044
00:48:54,933 --> 00:48:58,866
IN A COURSE
OF SIX DAYS FROM MARCH 31ST,

1045
00:48:58,866 --> 00:49:05,100

THE FIRST H7N9 CASES
BEING REPORTED IN CHINA.

1046
00:49:05,100 --> 00:49:08,200
A CHINESE GROUP
SEQUENCED THE GENOME.

1047
00:49:08,200 --> 00:49:11,833
WE WERE ABLE TO DOWNLOAD
THE SEQUENCE DIGITALLY.

1048
00:49:11,833 --> 00:49:15,900
WE STARTED THE SYNTHESIS
ON APRIL 1ST.

1049
00:49:15,900 --> 00:49:19,966
AND ON APRIL 6TH,
THE FIRST VACCINE ISOLATES

1050
00:49:19,966 --> 00:49:22,200
WERE RECOVERED.

1051
00:49:22,200 --> 00:49:24,833
NOVARTIS AND THEIR NEW CELL LINE
FACILITY IN NORTH CAROLINA

1052
00:49:24,833 --> 00:49:27,733
SCALED UP THE PRODUCTION,

1053
00:49:27,733 --> 00:49:30,000
WENT INTO CLINICAL TESTING,

1054
00:49:30,000 --> 00:49:32,733
AND NOW THE U.S.
IS STOCKPILING THIS VACCINE,

1055
00:49:32,733 --> 00:49:36,433
WHICH IS OUR FIRST
SYNTHETIC DNA-BASED VACCINE.

1056

00:49:36,433 --> 00:49:40,233

AND IT'S ALSO THE FIRST TIME
WE'VE HAD A FLU VACCINE

1057

00:49:40,233 --> 00:49:42,866

BEING STOCKPILED
AND READY IN THE U.S.

1058

00:49:42,866 --> 00:49:45,300

BEFORE THERE'S EVER AN INFECTION
IN THE U.S.

1059

00:49:45,300 --> 00:49:49,100

THEY'VE BEEN IN
HONG KONG, CHINA, MALAYSIA,

1060

00:49:49,100 --> 00:49:52,633

AND THEY WILL SHOW UP HERE
SOONER OR LATER,

1061

00:49:52,633 --> 00:49:54,833

BUT NOW THAT THE VACCINE
IS READY,

1062

00:49:54,833 --> 00:49:58,333

HOPEFULLY A PANDEMIC
CAN BE TOTALLY PREVENTED.

1063

00:49:58,333 --> 00:50:01,666

SO THE NEXT STEPS IS MAYBE
COMBINING THESE THINGS.

1064

00:50:01,666 --> 00:50:04,566

WE CAN ACTUALLY SEND
THE FLU VACCINE

1065

00:50:04,566 --> 00:50:07,166

AROUND THE WORLD
AT THE SPEED OF LIGHT

1066
00:50:07,166 --> 00:50:09,000
IN A FRACTION OF A SECOND.

1067
00:50:09,000 --> 00:50:11,466
AND SO IF YOU HAD
RECEIVING UNITS

1068
00:50:11,466 --> 00:50:14,100
EVEN ON YOUR HOME COMPUTER,

1069
00:50:14,100 --> 00:50:16,600
YOU COULD DOWNLOAD INSULIN,

1070
00:50:16,600 --> 00:50:21,400
YOU COULD DOWNLOAD
OUR, UH, VACCINES

1071
00:50:21,400 --> 00:50:23,966
OR A FLU VACCINE.

1072
00:50:23,966 --> 00:50:26,833
AND IF WE HAVE THESE
DISTRIBUTED ENOUGH,

1073
00:50:26,833 --> 00:50:29,800
IT SHOULD TOTALLY PREVENT

1074
00:50:29,800 --> 00:50:33,266
ANY FUTURE PANDEMICS.

1075
00:50:33,266 --> 00:50:37,833
SO FOR NASA, A COMBINATION
OF THESE THINGS MAY--

1076
00:50:37,833 --> 00:50:41,733
CERTAINLY USING GENOMICS
TO IDENTIFY AND PREVENT

1077

00:50:41,733 --> 00:50:44,766
DISEASE RISK IN THE FUTURE

1078
00:50:44,766 --> 00:50:46,666
BOTH HERE ON EARTH

1079
00:50:46,666 --> 00:50:48,966
AND ON OTHER PLANETS.

1080
00:50:48,966 --> 00:50:54,133
AND OBVIOUSLY,
DESIGN IS AN OPEN ISSUE.

1081
00:50:54,133 --> 00:50:58,266
MAYBE WE WANT TO MAKE
PHOTOSYNTHETIC ANIMALS

1082
00:50:58,266 --> 00:51:01,866
OR EVEN
PHOTOSYNTHETIC HUMANS

1083
00:51:01,866 --> 00:51:04,966
IF THEY ARE BALD
AND HAVE ENOUGH SKIN AVAILABLE.

1084
00:51:04,966 --> 00:51:06,300
SO THANK YOU VERY MUCH.

1085
00:51:06,300 --> 00:51:09,300
[applause]

1086
00:51:13,733 --> 00:51:17,066
- THANK YOU, DR. VENTER.
- SURE.

1087
00:51:17,066 --> 00:51:19,866
- SO WE HAVE TIME
FOR A COUPLE OF QUESTIONS.

1088

00:51:19,866 --> 00:51:21,800
IF YOU HAVE A QUESTION,
PLEASE RAISE YOUR HAND,

1089
00:51:21,800 --> 00:51:23,566
WAIT FOR THE MICROPHONE,

1090
00:51:23,566 --> 00:51:26,366
AND PLEASE STAND
WHEN YOU ASK THE QUESTION.

1091
00:51:29,900 --> 00:51:32,300
- I HAVE A QUESTION BACK HERE.
- WHERE?

1092
00:51:32,300 --> 00:51:33,433
- CRAIG, I HAVE A QUESTION
OVER HERE.

1093
00:51:33,433 --> 00:51:35,833
- OH, OKAY.
- I THINK THIS IS AMAZING

1094
00:51:35,833 --> 00:51:37,933
THAT YOU WERE ABLE TO MAKE
A SYNTHETIC ORGANISM,

1095
00:51:37,933 --> 00:51:41,266
I.E. SYNTHESIZED DNA,
BUT I'M A LITTLE BIT SURPRISED

1096
00:51:41,266 --> 00:51:43,300
THAT YOU'RE SURPRISED
THAT IT WORKED.

1097
00:51:43,300 --> 00:51:46,700
I MEAN, WHAT WOULD HAVE HAPPENED
OTHERWISE?

1098
00:51:46,700 --> 00:51:48,533

I MEAN,
YOU MADE THE DNA.

1099
00:51:48,533 --> 00:51:51,266
IT WAS CHEMICALLY IDENTICAL
TO DEOXYRIBONUCLEIC ACID.

1100
00:51:51,266 --> 00:51:54,333
HOW COULD IT
NOT HAVE WORKED?

1101
00:51:54,333 --> 00:51:57,500
- I'M NOT SURPRISED
THAT IT WORKED IN THE END.

1102
00:51:57,500 --> 00:52:00,233
IN FACT,
IF YOU LOOK AT MY BOOK,

1103
00:52:00,233 --> 00:52:03,066
THE FIRST THIRD OF IT
IS THE HISTORY OF THIS FIELD.

1104
00:52:03,066 --> 00:52:05,800
AND A FRENCHMAN WROTE A BOOK
A HUNDRED YEARS AGO

1105
00:52:05,800 --> 00:52:08,700
SAYING THAT SYNTHETIC LIFE
WAS OBVIOUS

1106
00:52:08,700 --> 00:52:12,133
AND WAS GOING TO HAPPEN
ONCE OUR IMPROVED KNOWLEDGE

1107
00:52:12,133 --> 00:52:15,833
OF MACROMOLECULES OCCURRED
AND THAT IT WAS--

1108
00:52:15,833 --> 00:52:18,500

HE WAS SO CERTAIN, HE SAID
PEOPLE SHOULD NOT BE SURPRISED

1109
00:52:18,500 --> 00:52:20,333
WHEN IT HAPPENED.

1110
00:52:20,333 --> 00:52:22,733
HE WAS IN THE POINT OF VIEW
OF DEALING WITH

1111
00:52:22,733 --> 00:52:25,100
ALL THE TECHNICAL DETAILS
OF DOING THIS.

1112
00:52:25,100 --> 00:52:28,966
THE TRANSPLANTATION OF GETTING
THE GENOME INTO THE CELL

1113
00:52:28,966 --> 00:52:31,966
UNDER THE RIGHT CONDITIONS,

1114
00:52:31,966 --> 00:52:35,100
IT MADE ME APPRECIATE
HOW AND WHY

1115
00:52:35,100 --> 00:52:37,266
RESTRICTION ENZYMES EVOLVED.

1116
00:52:37,266 --> 00:52:40,566
IF YOU HAD A MEAL OF FISH

1117
00:52:40,566 --> 00:52:44,766
AND ABSORBING BILLIONS OF COPIES
OF THE FISH GENOME,

1118
00:52:44,766 --> 00:52:48,733
YOU STARTED TO REARRANGE
YOUR OWN GENOME,

1119

00:52:48,733 --> 00:52:50,766
WHICH IS WHAT HAPPENS
IN THE BACTERIAL WORLD

1120
00:52:50,766 --> 00:52:54,466
IF THEY DON'T HAVE THE RIGHT
RESTRICTION ENZYMES,

1121
00:52:54,466 --> 00:52:57,466
EVOLUTION WOULD BE
VERY SURPRISINGLY DIFFERENT.

1122
00:52:57,466 --> 00:52:59,933
WE'D PROBABLY BE A LOT MORE
CAREFUL ABOUT WHAT WE EAT.

1123
00:52:59,933 --> 00:53:01,466
[laughter]

1124
00:53:01,466 --> 00:53:04,533
SO IT'S NOT SURPRISING
THAT IT WORKED IN THEORY.

1125
00:53:04,533 --> 00:53:06,733
WHEN YOU WORK ON TEN YEARS
TO OVERCOME

1126
00:53:06,733 --> 00:53:09,600
THE PRACTICAL LIMITATIONS
OF MAKING IT HAPPEN,

1127
00:53:09,600 --> 00:53:12,200
THAT WAS THE SURPRISING PART.
- LET ME ASK

1128
00:53:12,200 --> 00:53:14,066
A FOLLOW-UP QUESTION,
AND THAT HAS TO DO WITH

1129
00:53:14,066 --> 00:53:16,100

NOT ONLY RESTRICTION ENZYMES

1130

00:53:16,100 --> 00:53:19,233
BUT ALL THE DIFFERENT TYPES
OF RNAs THAT ARE INVOLVED

1131

00:53:19,233 --> 00:53:21,333
AND ALL THE DIFFERENT
CONTROL FACTORS,

1132

00:53:21,333 --> 00:53:24,266
PROMOTERS,
ALL THE DIFFERENT SILENCERS

1133

00:53:24,266 --> 00:53:26,266
THAT ARE IN A COMPLEX GENOME

1134

00:53:26,266 --> 00:53:28,400
THAT WE MOVE BEYOND
A YEAST GENOME

1135

00:53:28,400 --> 00:53:31,700
OR A SINGLE-CELL
PROKARYOTIC GENOME

1136

00:53:31,700 --> 00:53:34,333
INTO SOMETHING COMPLEX--

1137

00:53:34,333 --> 00:53:37,333
DO YOU REALLY SEE
A FUTURE THERE

1138

00:53:37,333 --> 00:53:40,133
IF YOU'RE JUST DABBLING
IN DNA?

1139

00:53:40,133 --> 00:53:42,466
- WELL, THOSE PEOPLE

1140

00:53:42,466 --> 00:53:45,333
WHO MEASURE
EPIGENETIC PHENOMENON,

1141
00:53:45,333 --> 00:53:47,633
I HAVE A SAYING FOR THEM--

1142
00:53:47,633 --> 00:53:49,500
EPIGENETICS
IS STILL GENETICS.

1143
00:53:49,500 --> 00:53:52,266
IT STARTED WITH THE GENOME,

1144
00:53:52,266 --> 00:53:54,266
AND ALL THESE
EPIGENETIC PHENOMENON

1145
00:53:54,266 --> 00:53:58,366
CAME FROM MOLECULES PRODUCED
FROM THAT BASIC GENETIC CODE.

1146
00:53:58,366 --> 00:54:02,866
THAT'S WHAT OUR CHALLENGE IS
WITH THIS GIANT COMPUTE

1147
00:54:02,866 --> 00:54:05,633
OF GETTING SO WE CAN PREDICT
FROM THE PRIMARY CODE--

1148
00:54:05,633 --> 00:54:07,566
'CAUSE THAT'S HOW YOUR CELLS
WORK, YOU KNOW?

1149
00:54:07,566 --> 00:54:09,566
YOU HAVE 100 TRILLION CELLS.

1150
00:54:09,566 --> 00:54:11,766
THEY READ YOUR GENETIC CODE,

1151

00:54:11,766 --> 00:54:15,233

AND THEY PRODUCE VIRTUALLY
EVERYTHING ABOUT YOU.

1152

00:54:15,233 --> 00:54:17,933

WE'VE BEEN REDUCED
IN MEDICINE

1153

00:54:17,933 --> 00:54:21,233

TO MEASURING A FEW
OF THE LIMITED GROSS CHANGES

1154

00:54:21,233 --> 00:54:23,233

FROM THAT.

1155

00:54:23,233 --> 00:54:25,666

WE WANT TO GET SO WE CAN PREDICT
ALL OF THOSE

1156

00:54:25,666 --> 00:54:28,800

FROM UNDERSTANDING
THE GENETIC CODE ITSELF.

1157

00:54:30,966 --> 00:54:33,833

YES.

- YES, I HAD A QUESTION

1158

00:54:33,833 --> 00:54:36,700

REGARDING WHEN YOU'RE SENDING
THE DNA INFORMATION,

1159

00:54:36,700 --> 00:54:39,500

SAY, FROM MARS
OR SO THAT PEOPLE CAN USE IT,

1160

00:54:39,500 --> 00:54:40,866

YOU KNOW, TO DOWNLOAD
IN THE FUTURE--

1161

00:54:40,866 --> 00:54:42,233
- WE HAVEN'T DONE THAT YET,
BUT...

1162
00:54:42,233 --> 00:54:44,466
[laughs]
- [laughs]

1163
00:54:44,466 --> 00:54:46,966
BUT YOU HAD--YOU HAD DONE
SAMPLES IN THE DESERT,

1164
00:54:46,966 --> 00:54:48,500
YOU HAD SAID...
- YEAH.

1165
00:54:48,500 --> 00:54:51,433
- THAT ACTUALLY DID WORK.
WHAT KIND OF INFORMATION LOSS

1166
00:54:51,433 --> 00:54:54,166
WAS THERE WHEN--
WHEN IT WAS SENT?

1167
00:54:54,166 --> 00:54:56,066
WAS THERE ANY SORT OF--

1168
00:54:56,066 --> 00:54:57,966
YOU KNOW, WHEN YOU THINK ABOUT
COPYING SOMETHING,

1169
00:54:57,966 --> 00:55:00,100
THERE'S ALWAYS JUST A LITTLE BIT
THAT--THAT MIGHT BE LOST THERE.

1170
00:55:00,100 --> 00:55:01,366
- YEAH.

1171
00:55:01,366 --> 00:55:03,800
WITH THE SEQUENCING THAT

WE WERE DOING IN THE DESERT,

1172

00:55:03,800 --> 00:55:07,100

THERE WAS SO MUCH REDUNDANCY
THAT WASN'T AN ISSUE.

1173

00:55:07,100 --> 00:55:11,233

ACTUALLY, A BIGGER PROBLEM WAS
THE BIOLOGICAL DIVERSITY

1174

00:55:11,233 --> 00:55:13,433

SO THAT WE WOULD NOT--

1175

00:55:13,433 --> 00:55:15,433

FROM THE SAMPLING
WE DID IN THE DESERT

1176

00:55:15,433 --> 00:55:17,433

AND THE AMOUNT OF SEQUENCING
WE DID THERE,

1177

00:55:17,433 --> 00:55:19,833

WE DIDN'T EXPECT
THIS TREMENDOUS DIVERSITY

1178

00:55:19,833 --> 00:55:21,566

OF EUKARYOTES
AND PROKARYOTES

1179

00:55:21,566 --> 00:55:24,333

THAT LOOK, ON THE BACK
OF THIS QUARTZ ROCK,

1180

00:55:24,333 --> 00:55:27,633

LIKE A SIMPLE ALGAE COLONY.

1181

00:55:27,633 --> 00:55:31,433

SO WE WOULD HAVE HAD TO SEQUENCE
IN GREATER DEPTH

1182
00:55:31,433 --> 00:55:33,533
TO BE ABLE TO RECONSTRUCT
THE GENOMES

1183
00:55:33,533 --> 00:55:35,766
FROM ALL THOSE DIFFERENT SPECIES
THERE.

1184
00:55:35,766 --> 00:55:37,233
SO IF WE'RE EVER SAMPLING--

1185
00:55:37,233 --> 00:55:39,633
IF WE'RE SAMPLING ON MARS

1186
00:55:39,633 --> 00:55:41,833
AND THERE'S GREAT
BIOLOGICAL DIVERSITY,

1187
00:55:41,833 --> 00:55:44,266
AND THERE'S NO REASON
TO EXPECT THERE WOULDN'T BE,

1188
00:55:44,266 --> 00:55:47,833
WE HAVE TO HAVE A MASSIVE AMOUNT
OF SEQUENCING

1189
00:55:47,833 --> 00:55:51,266
IF WE ACTUALLY WANT
TO RE-CREATE THOSE ORGANISMS.

1190
00:55:51,266 --> 00:55:53,700
IF YOU ISOLATE THEM
AND THEN SEQUENCE THEM,

1191
00:55:53,700 --> 00:55:55,233
THEN IT'S MUCH SIMPLER,

1192
00:55:55,233 --> 00:55:57,800
BUT THERE WAS REALLY NO LOSS OF

SIGNAL THAT WE COULD HAVE SEEN.

1193

00:55:57,800 --> 00:56:00,066

IT'S JUST SENDING DNA
UP TO THE CLOUD

1194

00:56:00,066 --> 00:56:02,600

AND THEN RECAPTURING IT.

1195

00:56:04,566 --> 00:56:05,833

YES.

1196

00:56:05,833 --> 00:56:07,833

- YOU MENTIONED
THAT ONE OF YOUR GOALS

1197

00:56:07,833 --> 00:56:09,833

WAS--YOU'D HAVE
IN THE NEXT FEW WEEKS--

1198

00:56:09,833 --> 00:56:12,966

YOU'RE REORGANIZING THE GENOME
TO COMPARTMENTS

1199

00:56:12,966 --> 00:56:14,933

BASED ON FUNCTION.

1200

00:56:14,933 --> 00:56:17,066

I WAS WONDERING,
IF BY DOING THAT,

1201

00:56:17,066 --> 00:56:20,966

ARE YOU AVOIDING--ARE--ARE YOU
REMOVING SOME OF THE--

1202

00:56:20,966 --> 00:56:23,800

ARE YOU--ARE YOU CAUSING
A PROBLEM

1203

00:56:23,800 --> 00:56:27,133
WITH THE RANDOM RECOMBINATION
THAT MIGHT CALL--

1204
00:56:27,133 --> 00:56:29,266
OR THAT HAPPENS BETWEEN--

1205
00:56:29,266 --> 00:56:32,566
DURING SEQUENCING THAT--

1206
00:56:32,566 --> 00:56:37,066
BY--BY HAVING
THE--THE--THE GENE--

1207
00:56:37,066 --> 00:56:39,466
GENOME IN A RANDOM SITUATION

1208
00:56:39,466 --> 00:56:41,933
OR RANDOM ORGANIZATION
AROUND THE GENOME,

1209
00:56:41,933 --> 00:56:45,666
THEN IF THERE IS
RANDOM RECOMBINATION,

1210
00:56:45,666 --> 00:56:48,166
THEN YOU HAVE--
STILL HAVE SOME GENES

1211
00:56:48,166 --> 00:56:51,433
THAT ARE STILL REPLICATING
THE SAME THINGS.

1212
00:56:51,433 --> 00:56:54,033
- IN MOST
OF THESE BACTERIAL SPECIES,

1213
00:56:54,033 --> 00:56:56,033
THERE'S NOT A LOT
OF RECOMBINATION,

1214

00:56:56,033 --> 00:56:58,000

BUT IT CERTAINLY CAN OCCUR,

1215

00:56:58,000 --> 00:56:59,833

BUT I DON'T THINK THAT

WOULD LEAD TO IT.

1216

00:56:59,833 --> 00:57:01,433

THE BIGGEST CHALLENGE IS

1217

00:57:01,433 --> 00:57:03,233

THERE ARE THESE

HIGHER ORDER STRUCTURES.

1218

00:57:03,233 --> 00:57:06,666

FOR EXAMPLE,

ON A CIRCULAR GENOME,

1219

00:57:06,666 --> 00:57:08,700

THERE'S AN ORIGIN OF REPLICATION

1220

00:57:08,700 --> 00:57:12,200

AND THE GENETIC CODE GETS

READ OUT FROM THERE IN A CIRCLE.

1221

00:57:12,200 --> 00:57:15,300

AND IF YOU MOVE THAT ORIGIN

OF REPLICATION AROUND TOO MUCH

1222

00:57:15,300 --> 00:57:18,466

OR DON'T HAVE SYMMETRY

AROUND IT,

1223

00:57:18,466 --> 00:57:21,000

IT GETS

SO YOU DON'T HAVE LIFE.

1224

00:57:23,533 --> 00:57:24,933

WHERE ARE WE?

1225

00:57:24,933 --> 00:57:29,633
- AS GENETIC MATERIAL
BECOMES SYNTHESIZABLE

1226

00:57:29,633 --> 00:57:31,500
AND TRANSMISSIBLE,

1227

00:57:31,500 --> 00:57:33,900
WHAT ISSUES
DO YOU SEE ARISING

1228

00:57:33,900 --> 00:57:37,066
IN TERMS OF OWNERSHIP?

1229

00:57:39,033 --> 00:57:43,333
- DEPENDS WHAT YOU MEAN
BY OWNERSHIP.

1230

00:57:43,333 --> 00:57:45,200
YOU JUST LEFT
YOUR FINGERPRINTS

1231

00:57:45,200 --> 00:57:47,200
AND A LOT OF DNA
ON THE MICROPHONE.

1232

00:57:47,200 --> 00:57:50,366
WE COULD SEQUENCE
YOUR GENOME FROM THAT.

1233

00:57:52,466 --> 00:57:56,333
YOU DON'T OWN
THE MICROPHONE, UM...

1234

00:57:56,333 --> 00:57:58,800
YOU KNOW, SO I THINK
THESE ARE CONCEPTS

1235

00:57:58,800 --> 00:58:02,100

THAT ARE GONNA BE
RAPIDLY OUTDATED

1236

00:58:02,100 --> 00:58:04,633

BY THE PROGRESSION

1237

00:58:04,633 --> 00:58:08,200

OF THE INFORMATION UNIVERSE
THAT WE'RE IN.

1238

00:58:08,200 --> 00:58:10,966

WHAT YOU WANT
IS NOT OWNERSHIP.

1239

00:58:10,966 --> 00:58:13,366

YOU WANT TO HAVE
SOME DEGREE OF CONTROL

1240

00:58:13,366 --> 00:58:15,433

WHAT CAN BE DONE
WITH YOUR DNA.

1241

00:58:15,433 --> 00:58:17,733

THAT'S FAR MORE IMPORTANT
THAN OWNERSHIP.

1242

00:58:21,500 --> 00:58:23,900

- SO IF YOU WANTED TO SEND
ONE OF THESE MACHINES OF YOURS

1243

00:58:23,900 --> 00:58:27,300

TO MARS TO SEQUENCE DNA,
HOW BIG IS IT, HOW HEAVY IS IT?

1244

00:58:27,300 --> 00:58:30,933

IS IT FEASIBLE TO DO IT
WITH YOUR CURRENT TECHNOLOGY?

1245

00:58:30,933 --> 00:58:32,866

- IT'S A GREAT QUESTION.

1246

00:58:32,866 --> 00:58:35,600

I THINK YOU'D WANT TO SHRINK
THEM DOWN A WHOLE LOT MORE,

1247

00:58:35,600 --> 00:58:39,833

AND THAT SHOULDN'T BE
THAT MUCH OF A CHALLENGE.

1248

00:58:39,833 --> 00:58:43,066

SEQUENCING BACTERIAL

1249

00:58:43,066 --> 00:58:46,366

AND SMALL EUKARYOTIC GENOMES
IS VERY DIFFERENT THAN--

1250

00:58:46,366 --> 00:58:49,400

IF THERE'S MARTIANS
WITH HUMAN-SIZE GENOMES,

1251

00:58:49,400 --> 00:58:54,000

THEN WE NEED MUCH BIGGER
TECHNOLOGY, UM...

1252

00:58:54,000 --> 00:58:58,100

THINGS LIKE THE...

1253

00:58:58,100 --> 00:59:00,233

THE LIFE TECHNOLOGIES,

1254

00:59:00,233 --> 00:59:03,266

TECHNOLOGY WHICH MEASURES
pH CHANGES

1255

00:59:03,266 --> 00:59:06,433

ASSOCIATED WITH ONE BASE
BEING ADDED

1256

00:59:06,433 --> 00:59:10,133

AND IS BASICALLY DONE
ON A COMPUTER CHIP

1257

00:59:10,133 --> 00:59:12,333

IS, BY DEFINITION,

1258

00:59:12,333 --> 00:59:14,566

VERY MINIATURIZED

1259

00:59:14,566 --> 00:59:17,666

AND DOESN'T RELY ON ANY OPTICS
FOR READING IT.

1260

00:59:17,666 --> 00:59:20,266

THE ILLUMINA SEQUENCERS,
WE ACTUALLY HAD TO HAVE

1261

00:59:20,266 --> 00:59:22,933

A TECHNICIAN COME OUT
TO THE MOJAVE DESERT

1262

00:59:22,933 --> 00:59:25,700

TO REALIGN THE OPTICS

1263

00:59:25,700 --> 00:59:27,800

JUST AFTER ROAD TRAVEL
OUT THERE.

1264

00:59:27,800 --> 00:59:31,900

SO THOSE INSTRUMENTS WOULD NOT
BE VERY GOOD FOR SPACE TRAVEL.

1265

00:59:31,900 --> 00:59:33,333

UH...

1266

00:59:33,333 --> 00:59:36,166

THERE'S NO REASON
ANY OF THESE TECHNOLOGIES

1267

00:59:36,166 --> 00:59:38,633

COULDN'T BE REDUCED
TO CHIP-BASED

1268

00:59:38,633 --> 00:59:40,733

AND MICROCHANNEL-BASED THINGS.

1269

00:59:40,733 --> 00:59:42,833

WE'RE, AT
THE PROOF OF CONCEPT STAGE,

1270

00:59:42,833 --> 00:59:45,200

JUST GETTING THEM TO WORK.

1271

00:59:45,200 --> 00:59:47,533

HOPEFULLY,
YOU'LL TAKE THAT ON.

1272

00:59:50,200 --> 00:59:53,933

- OKAY, SO YOU TALKED ABOUT
A SYNTHETIC MICROBIOME

1273

00:59:53,933 --> 00:59:56,833

WITH, LIKE, THE CONTEXT
OF SPACE EXPLORATION

1274

00:59:56,833 --> 00:59:58,766

WHICH I IMAGINE IS LIKE
AS ISOLATED

1275

00:59:58,766 --> 01:00:00,966

AS AN ENVIRONMENT
AS YOU CAN GET.

1276

01:00:00,966 --> 01:00:03,666

BUT IF YOU WERE TO ATTEMPT
TO HAVE ENGINEERED CELLS,

1277

01:00:03,666 --> 01:00:06,366
LIKE, LIVING IN A HUMAN GUT
ON EARTH,

1278
01:00:06,366 --> 01:00:09,733
HOW DO YOU PREVENT NATURAL CELLS
FROM OUTCOMPETING

1279
01:00:09,733 --> 01:00:12,333
AND REPLACING
THOSE ENGINEERED CELLS?

1280
01:00:12,333 --> 01:00:17,833
- SO IT'S
A VERY GOOD QUESTION.

1281
01:00:17,833 --> 01:00:19,433
AND I THINK IT ALL GETS INTO
CELLULAR DESIGN, YOU KNOW?

1282
01:00:19,433 --> 01:00:22,066
I THINK THAT'S GONNA BE
ONE OF THE BIGGEST,

1283
01:00:22,066 --> 01:00:24,866
MOST CHALLENGING FIELDS
GOING FORWARD,

1284
01:00:24,866 --> 01:00:26,966
BUT IT'S GONNA HAPPEN

1285
01:00:26,966 --> 01:00:29,733
STARTING WITH HAVING
ALL THIS DIGITAL INFORMATION

1286
01:00:29,733 --> 01:00:32,900
AND TRYING TO UNDERSTAND
WHAT IT'S TELLING US

1287
01:00:32,900 --> 01:00:35,366

TO BE ABLE TO GO BACK
AND DO THE DESIGN.

1288

01:00:35,366 --> 01:00:38,133
SO SOME OF THE SYNTHETIC
MICROORGANISMS

1289

01:00:38,133 --> 01:00:40,833
MAY BE, YOU KNOW--

1290

01:00:40,833 --> 01:00:42,833
WE CAN MAKE CELLS GROW
MUCH FASTER

1291

01:00:42,833 --> 01:00:46,566
AND OUTCOMPETE OTHER ORGANISMS,
AS WELL.

1292

01:00:46,566 --> 01:00:49,700
THE GOAL IS TO ELIMINATE

1293

01:00:49,700 --> 01:00:52,833
THEIR PATHOLOGICAL POTENTIAL

1294

01:00:52,833 --> 01:00:57,066
AND JUST HAVE THEM HAVE
THE BENEFICIAL METABOLISM.

1295

01:00:57,066 --> 01:01:01,766
SO WE HAVE A WAYS TO GO
WITH A DEGREE OF UNDERSTANDING

1296

01:01:01,766 --> 01:01:03,733
BUT I THINK
THERE'S GONNA BE--

1297

01:01:03,733 --> 01:01:06,500
JUST LIKE THE 767
AND OTHER AIRPLANES,

1298

01:01:06,500 --> 01:01:08,633

THERE'LL BE A FEW FAILURES

1299

01:01:08,633 --> 01:01:11,166

BEFORE WE HAVE IT
ALL SORTED OUT.

1300

01:01:14,000 --> 01:01:16,733

- THERE WAS A QUESTION SAYING
HOW YOU TRANSMITTED

1301

01:01:16,733 --> 01:01:19,466

ALL THIS DNA INFORMATION
FROM MARS

1302

01:01:19,466 --> 01:01:21,833

OR "SIMULATED" MARS.

1303

01:01:21,833 --> 01:01:24,433

IT MAY BE A FUTURE TRANSPORTER,
LIKE A "STAR TREK" TRANSPORTER,

1304

01:01:24,433 --> 01:01:28,533

OR IS IT A WAY OF WE COULD
EVENTUALLY SEND HUMANS

1305

01:01:28,533 --> 01:01:31,300

INTO FAR DEPTHS OF SPACE
AT THE SPEED OF LIGHT,

1306

01:01:31,300 --> 01:01:36,033

NOT BY PEOPLE, BUT BY
OUR SPECIALIZED CODE OF DNA

1307

01:01:36,033 --> 01:01:39,266

AND MAYBE BEING REASSEMBLED
SOMEWHERE ELSE?

1308

01:01:39,266 --> 01:01:41,300

- WELL, PEOPLE ARE A LITTLE BIT
CONCERNED WITH THAT,

1309

01:01:41,300 --> 01:01:43,100

'CAUSE MY GENOME'S
BEING BROADCAST

1310

01:01:43,100 --> 01:01:44,866

FOR ABOUT 15 YEARS
OUT THERE,

1311

01:01:44,866 --> 01:01:47,866

SO YOU MIGHT GET A LOT
OF CRAIG VENTERS COMING BACK

1312

01:01:47,866 --> 01:01:50,500

IF PEOPLE DO THAT EXPERIMENT.
[laughter]

1313

01:01:50,500 --> 01:01:53,400

BUT NO, YOU KNOW,

1314

01:01:53,400 --> 01:01:55,300

YOU CAN EASILY--

1315

01:01:55,300 --> 01:01:57,566

IF IT'S REALLY DISTANT
SPACE TRAVEL,

1316

01:01:57,566 --> 01:02:01,466

YOU COULD JUST SEND
EITHER

1317

01:02:01,466 --> 01:02:05,000

SOME STEM CELLS
THAT ARE SHIELDED IN LEAD

1318

01:02:05,000 --> 01:02:07,833

AND ASSUME THAT SOMEBODY,

1319

01:02:07,833 --> 01:02:09,666

IF THEY REACH
THE RIGHT ENVIRONMENT,

1320

01:02:09,666 --> 01:02:11,933

WOULD BE ABLE TO DO
THE TRANSPLANT AND BOOT THEM UP,

1321

01:02:11,933 --> 01:02:14,633

OR POTENTIALLY
JUST SEND CODE.

1322

01:02:14,633 --> 01:02:16,500

UH...

1323

01:02:16,500 --> 01:02:19,633

ONCE WE'RE
IN DIFFERENT PLACES

1324

01:02:19,633 --> 01:02:22,866

AND HAVE THINGS TO READ THE CODE
AND BOOT IT UP,

1325

01:02:22,866 --> 01:02:24,566

OR IF WE HAVE
MORE ADVANCED MACHINES,

1326

01:02:24,566 --> 01:02:26,833

WE CAN JUST SEND THOSE
AND BOOT IT UP.

1327

01:02:26,833 --> 01:02:29,633

IT WOULDN'T BE HARD TO DO THAT
IN TERRAFORMED PLANETS.

1328

01:02:29,633 --> 01:02:32,266

SENDING HUMANS
IS A LOT MORE CHALLENGING.

1329

01:02:34,500 --> 01:02:36,733
OKAY.

1330
01:02:36,733 --> 01:02:39,900
- SO PLEASE JOIN ME
IN THANKING DR. VENTER AGAIN

1331
01:02:39,900 --> 01:02:41,600
FOR AN EXCELLENT PRESENTATION.

1332
01:02:41,600 --> 01:02:44,600
[applause]