Open-ended fitness landscapes

Nathaniel Virgo

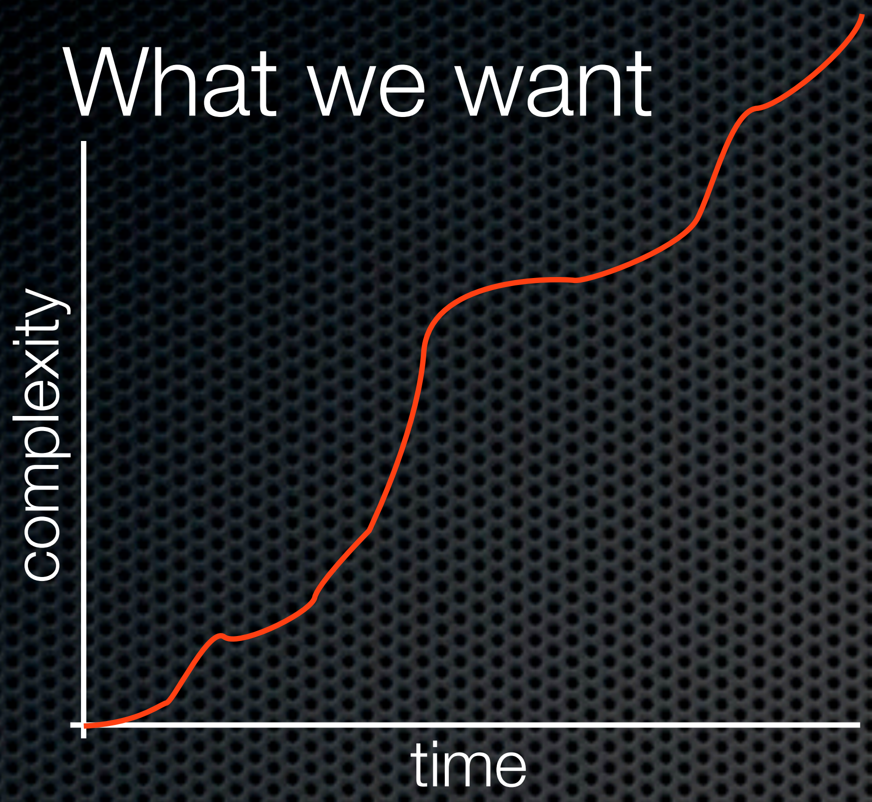
Earth-Life Science Institute,
Tokyo Institute of Technology

Overview

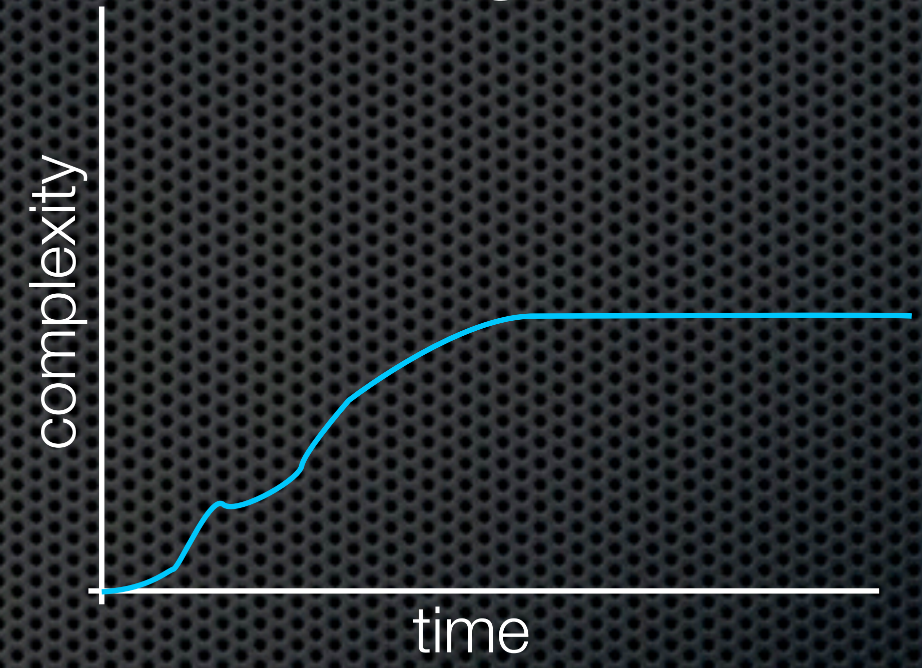
- I claim that
open-endedness is a property of fitness landscapes
and not so much a property of evolution itself
- I'll explain what this means
- And say a little bit about evolution of evolvability
- And then give an optimistic conclusion

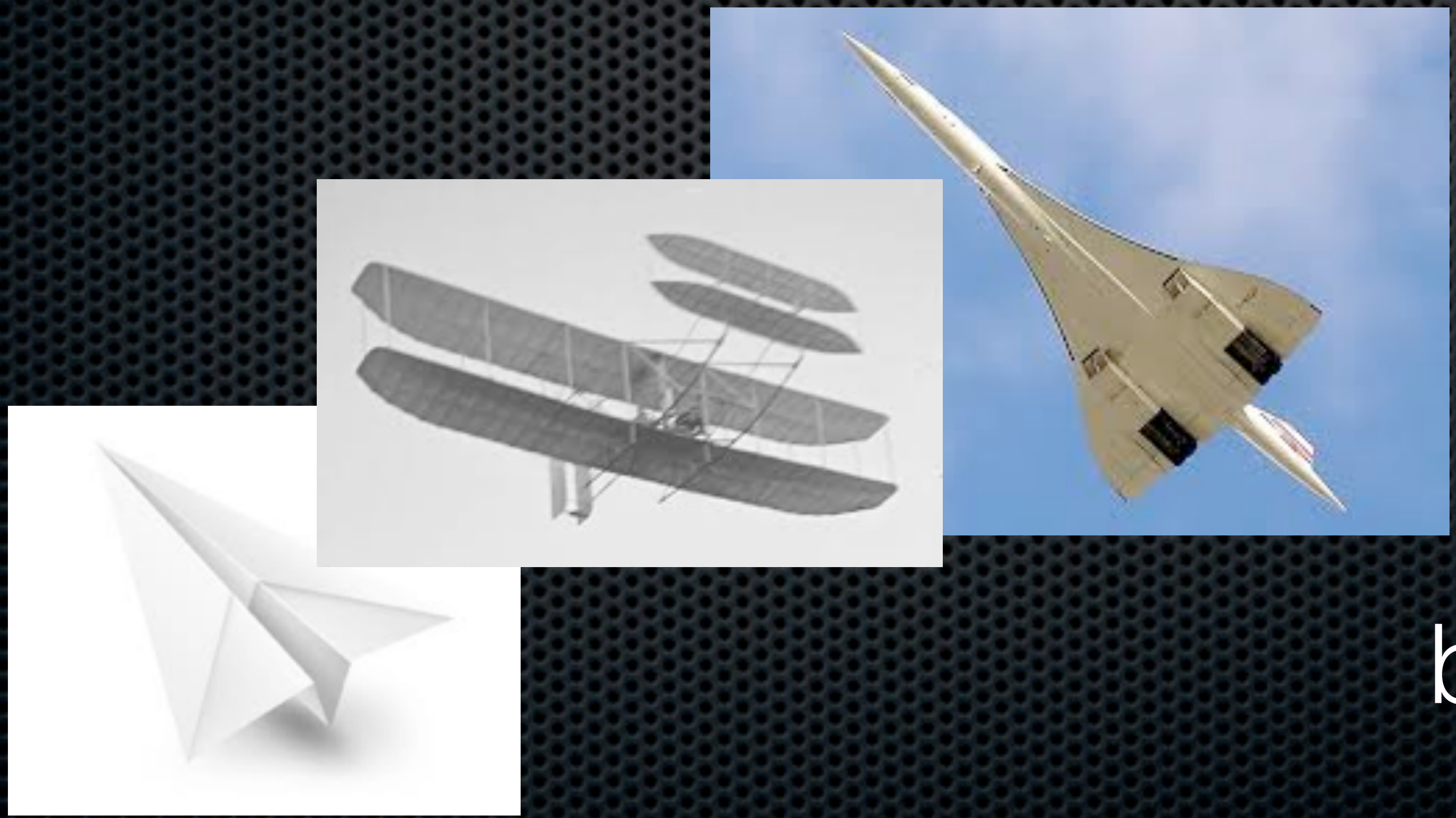
What is OEE anyway?

What we want



What we get





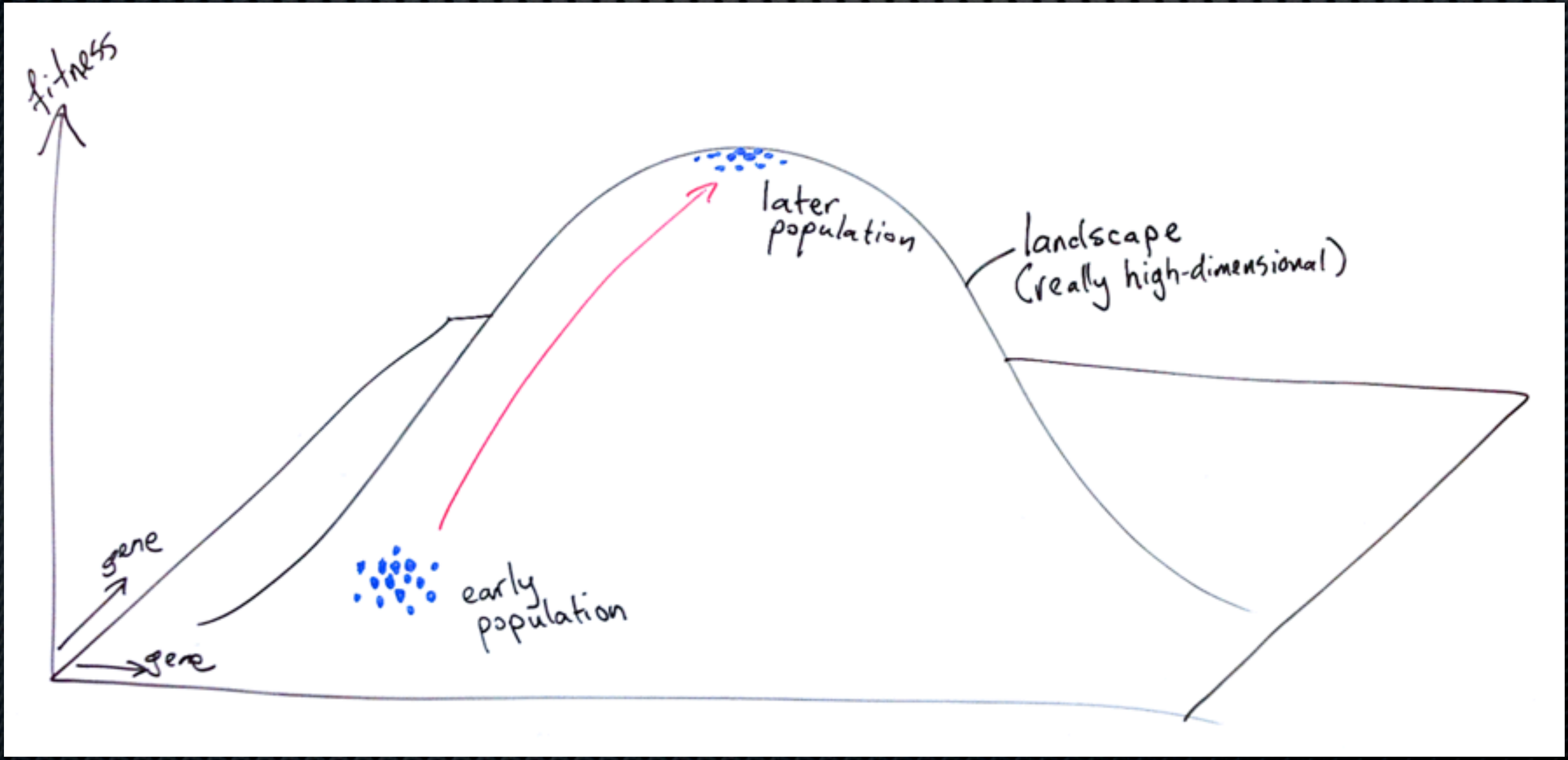
I think this is basically what it's about

Question

- We all believe that ecology is important
  - changing environments, coevolution, niche construction, ...
- But how much of this is **necessary** for OEE as defined on the previous slide?
- To find out, let's think about a static fitness landscape...

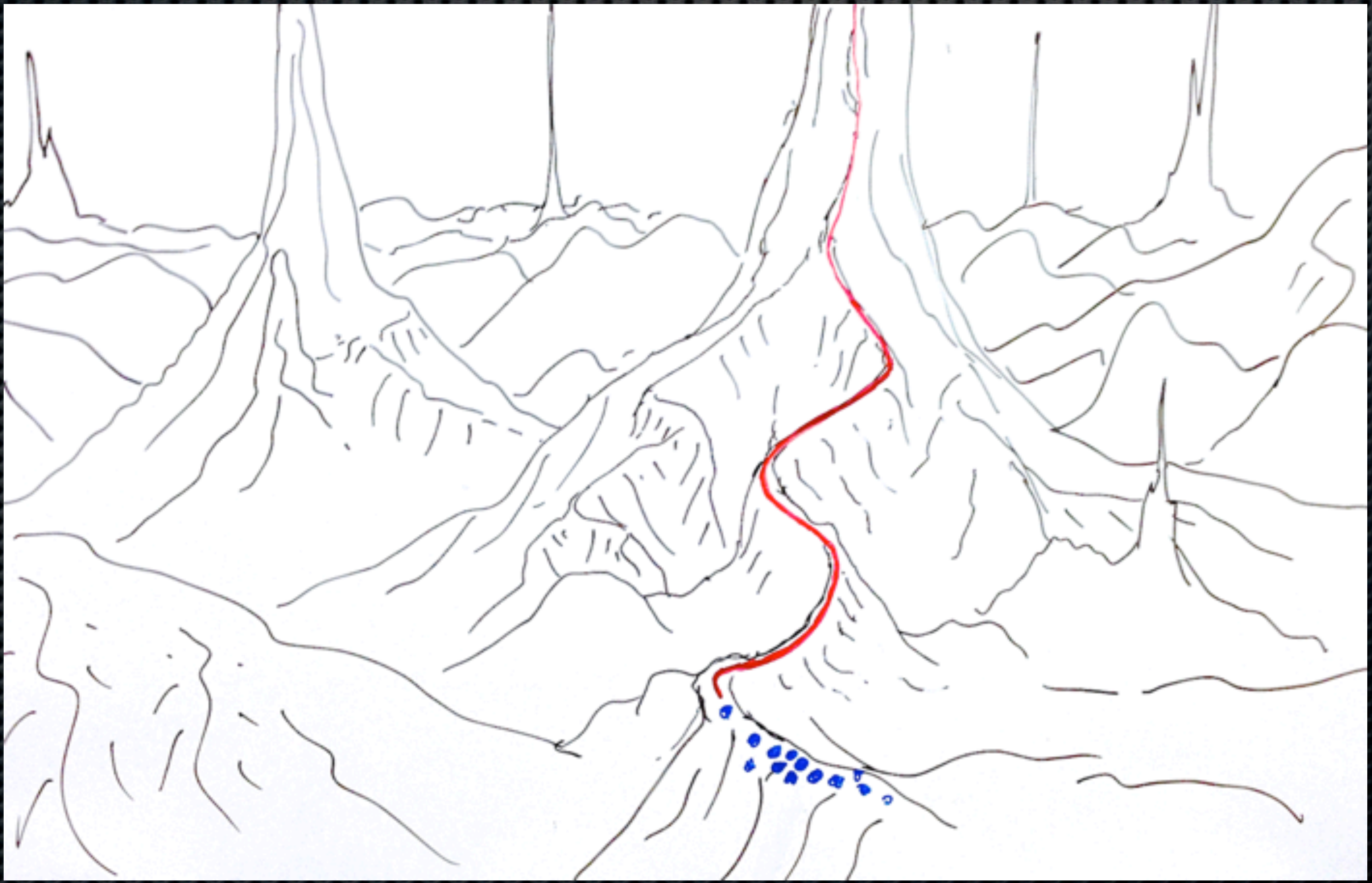
OEE as a question about fitness landscapes

- Consider a typical genetic algorithm



OEE as a question about fitness landscapes

- Now imagine the landscape looks like this



OEE as a question about fitness landscapes

- Reaching solutions of extreme complexity is easy,
  if there are solutions of extreme complexity that exist,
  and are more fit than simple solutions,
  and ***can be reached.***
- Many qualitatively different solutions can be found, if they exist and are reachable

What about complexity?

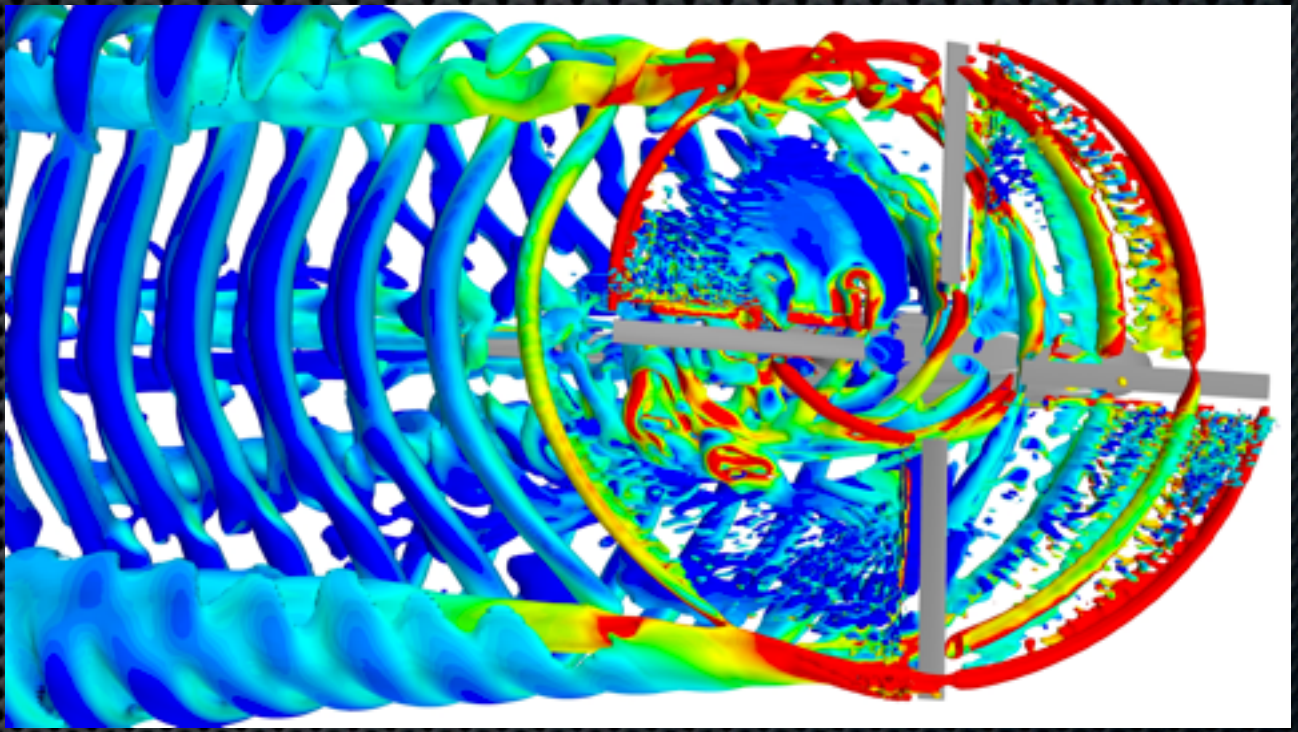
- What do I mean by complexity?
- Personally I’m most interested in *phenotypic* complexity, which is a bit easier to deal with...

Degrees of freedom

- In the physical world, there are many degrees of freedom, both in an organism's development and in its immediate environment
- DOF means something like
  “capacity to be changed in some non-trivial way”
- Hypothesis: DOFs open up “new places to go.”
- E.g. see the flight example...

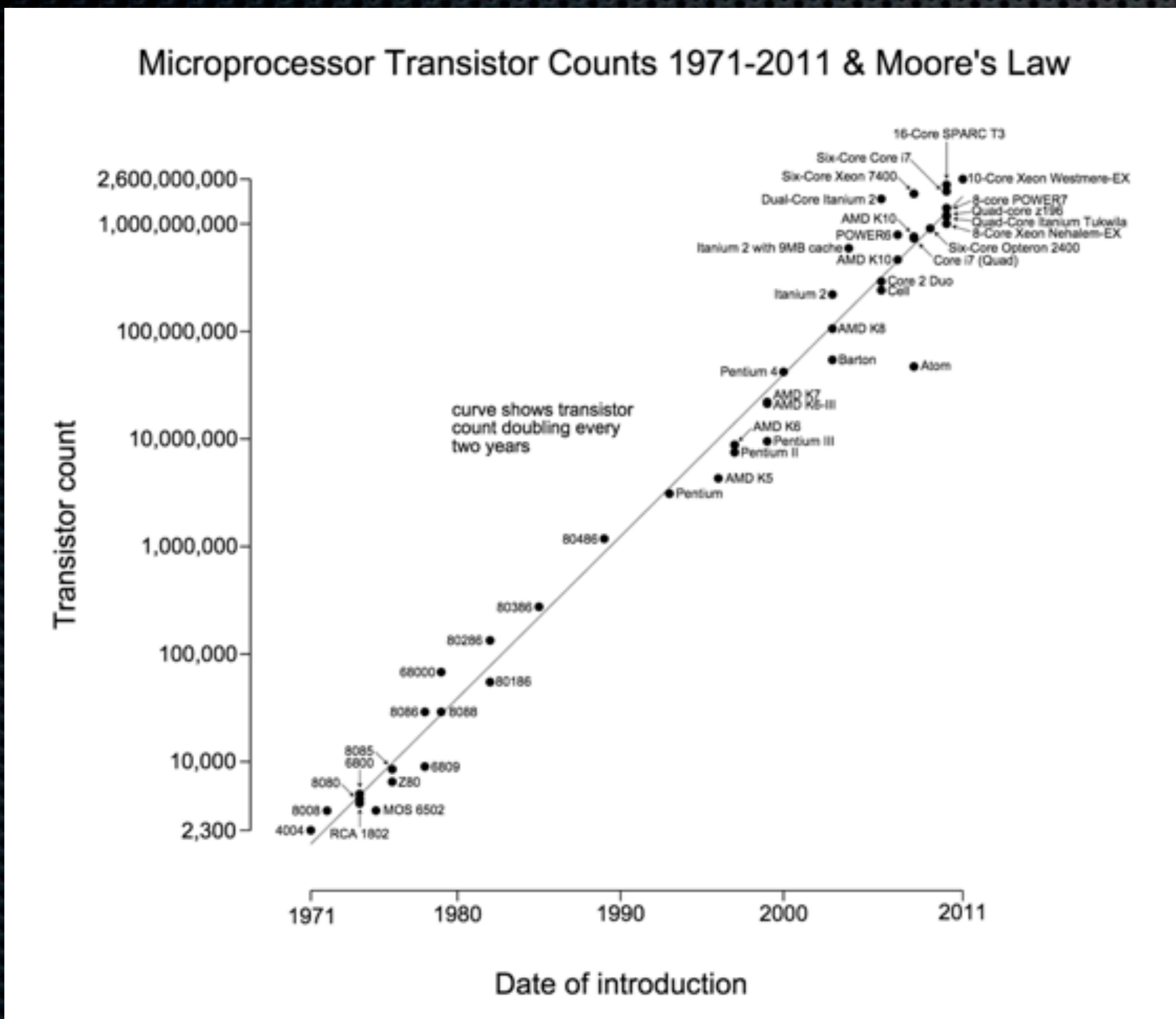
Flight has many DoFs

- Flight involves fluid mechanics - to simulate you need a huge mesh
- This computational complexity is fundamental!



- It is this that allows many qualitatively different solutions to exist

OEE and EOE
(Evolution of Evolvability)



- Exponential growth usually occurs as a result of positive feedback
- What positive feedbacks can drive exponential increase in complexity?

OEE and EOE

- Hypothesis: many non-trivial fitness landscapes have a *small evolvable region*
- (example on next slide)
- EOE allows that region to be found

- Hypothesis: EOE happens via lineage selection when populations are large
- unevolvable solutions out-competed by evolvable ones

What is the fitness landscape of C programs?

- Consider strings of characters, interpreted as C programs and evaluated at some task
- But actually there probably *are* evolvable regions of this landscape
- The code is written in a more evolvable language and then interpreted
- mutation in the interpreter = tough luck

```
char *s=”w{ebcWi)=@odSPf.kc=4UbE})3j/-
U_SXx-\>ZaLK.+1nll/=wz3-g6~YBYMR3
\$`3eO\=Wh&%JwMOO.'[M\"ug,Uv6i)>Q
...
...
v9yaRWu7aV:M}T*/Va_epUV7M#7q*xq$`
3eO\=Wh&%JwMOO.'[M\"ug,Uv6i)>Qv9y
aRWu7aV:M}T*/Va_epUV7M#7q*xq”;

int main() {/*succinct interpreter code
here*/}
```

OEE, EOE
and the origins of life

- Life is open-ended
- But it is also all about evolvability
- The DNA-RNA-protein system is a “small evolvable region” of chemical space
- Hypothesis: OEE and EOE are fundamental to the origins of life

Summary

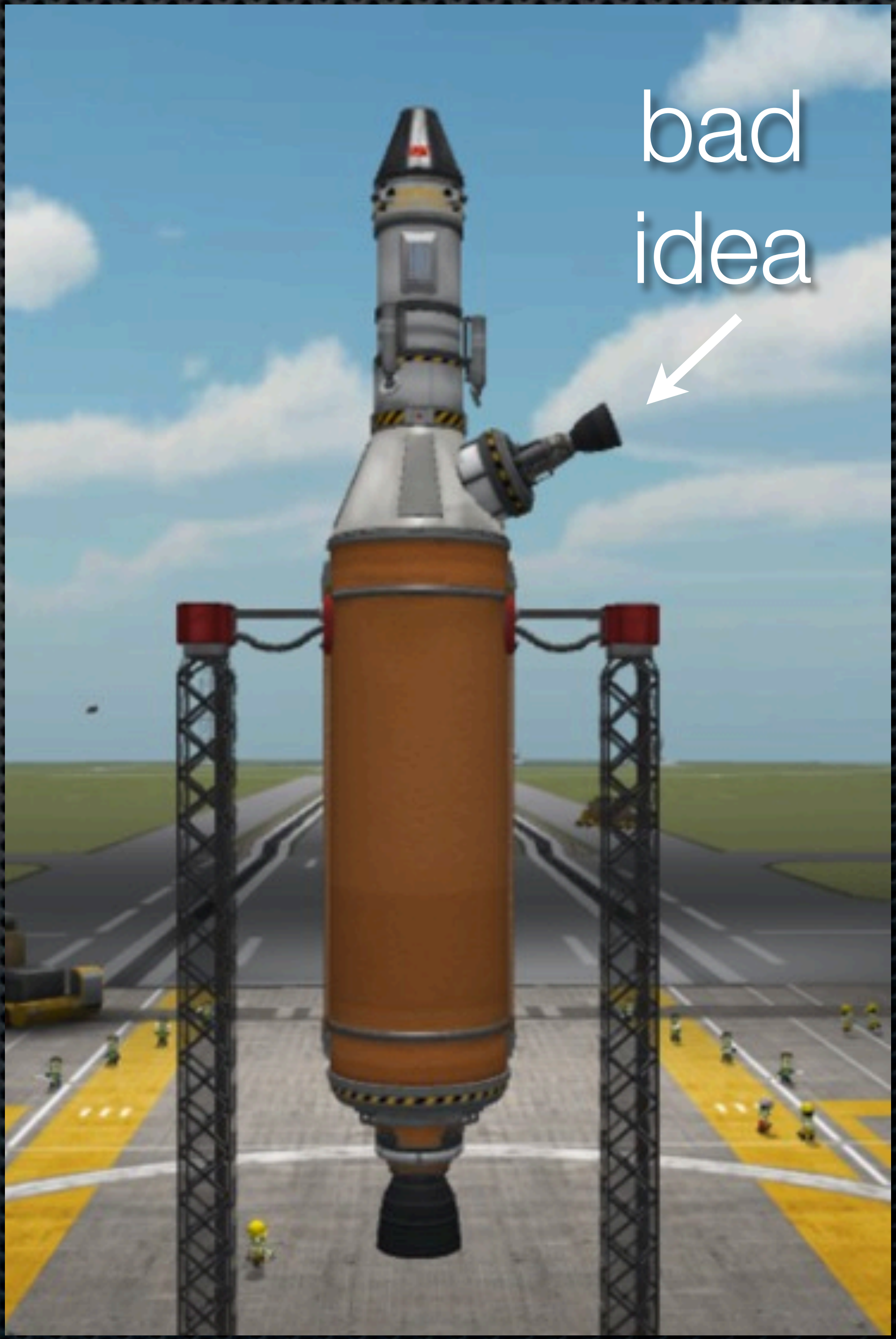
- Evolution won't go anywhere unless it has somewhere to go
- Perhaps what we need is a fitness landscape where *there is always somewhere new to go*
- With enough degrees of freedom and large enough populations, perhaps evolution can find these properties for itself

Tentative but optimistic conclusion

- Feedfoward neural nets and backprop initially seemed quite limited
- But with more computing power and some tricks to prevent convergence, they turned out to work well
- Perhaps the same is true of evolutionary computing
- Perhaps all we need for OEE are:
  - larger search spaces, more non-trivial fitness functions, larger populations, more computer time

Phenotypic complexity

- In the physical world, adding a little bit of extra complexity to a machine is usually a bad idea
- But *just the right* bit of extra complexity is often an improvement



Open-ended landscapes

- So we want a fitness landscape with these properties:
  - most changes that add complexity reduce fitness
  - but often there exists a mutation that increases both complexity and fitness
  - very high complexity, high fitness states exist and are reachable
  - low complexity, high fitness solutions don't exist, or aren't reachable