The evolutionary origin of complex features

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- “A long standing challenge to evolutionary theory has been whether it can explain the origin of complex organismal features.”

Phenotypes

- "Computational metabolism": Boolean functions with 1 or 2 arguments

AND	input-1	input-2	output
	0	0	0
	0	1	0
	1	0	0
	1	1	1

XOR	input-1	input-2	output
	0	0	0
	0	1	1
	1	0	1
	1	1	0

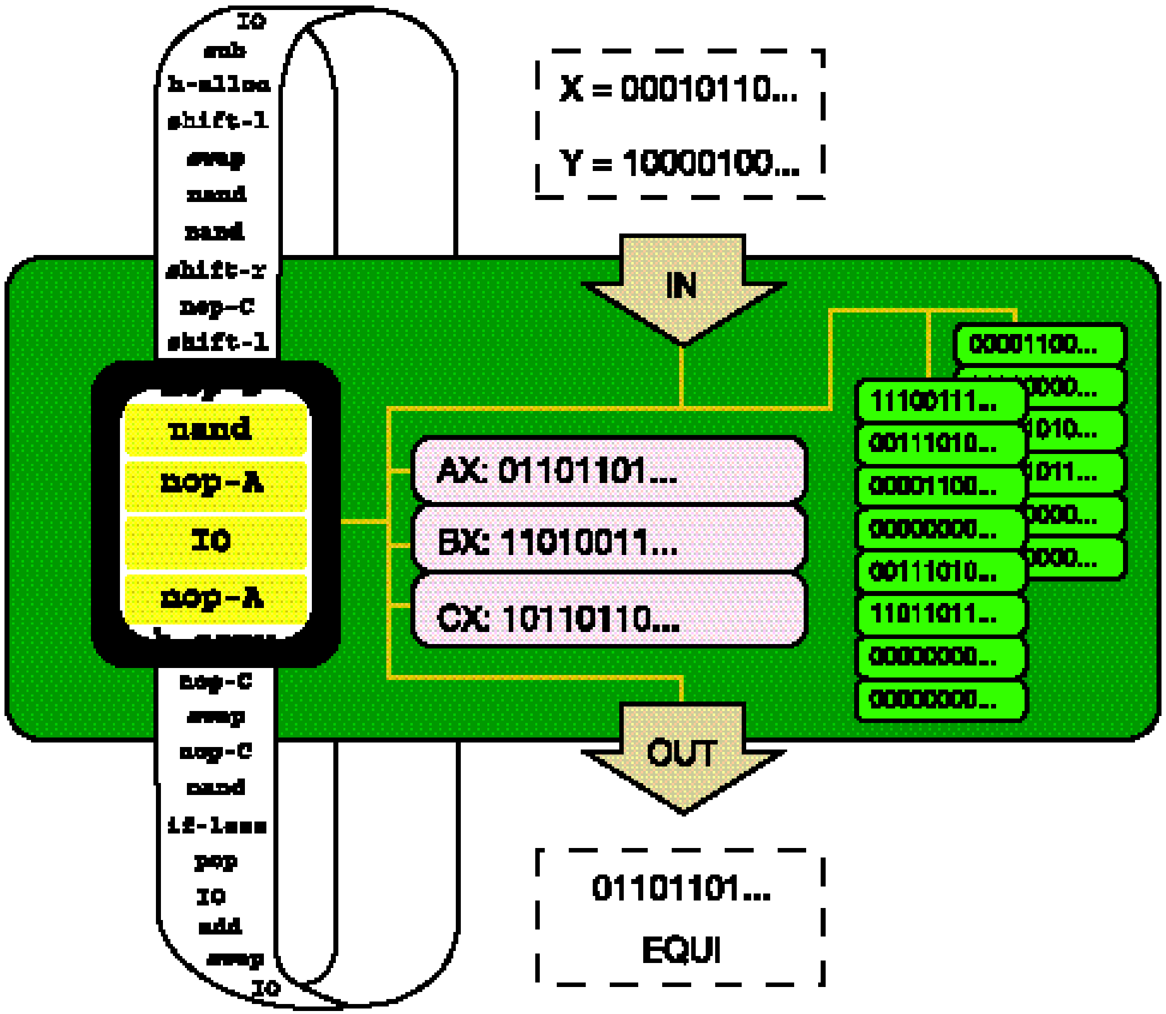
NOT	input-1	output
	0	1
	1	0

EQU	input-1	input-2	output
	0	0	1
	0	1	0
	1	0	0
	1	1	1

- Selfreplication

Genotypes

EQU						
#	Inst	AX	BX	CX	Stack	Output
1	IO	?	X	?	?	?
2	IO	?	X	Y	?	?
3	nop-C					
4	push	?	X	Y	X, ?	
5	nand	?	X nand Y	Y	X, ?	
6	swap	?	Y	X nand Y	X, ?	
7	nand	?	X or ~Y	X nand Y	X, ?	
8	swap	X or ~Y	?	X nand Y	X, ?	
9	nop-A					
10	pop	X or ~Y	X	X nand Y	?	
11	nand	X or ~Y	Y or ~X	X nand Y	?	
12	swap	X nand Y	Y or ~X	X or ~Y	?	
13	nop-C					
14	nand	X nand Y	X xor Y	X or ~Y	?	
15	push	X nand Y	X xor Y	X or ~Y	X xor Y, ?	
16	pop	X nand Y	X xor Y	X xor Y	?	
17	nop-C					
18	nand	X nand Y	X equ Y	X xor Y	?	
19	IO	X nand Y	Z	X xor Y	?	X equ Y

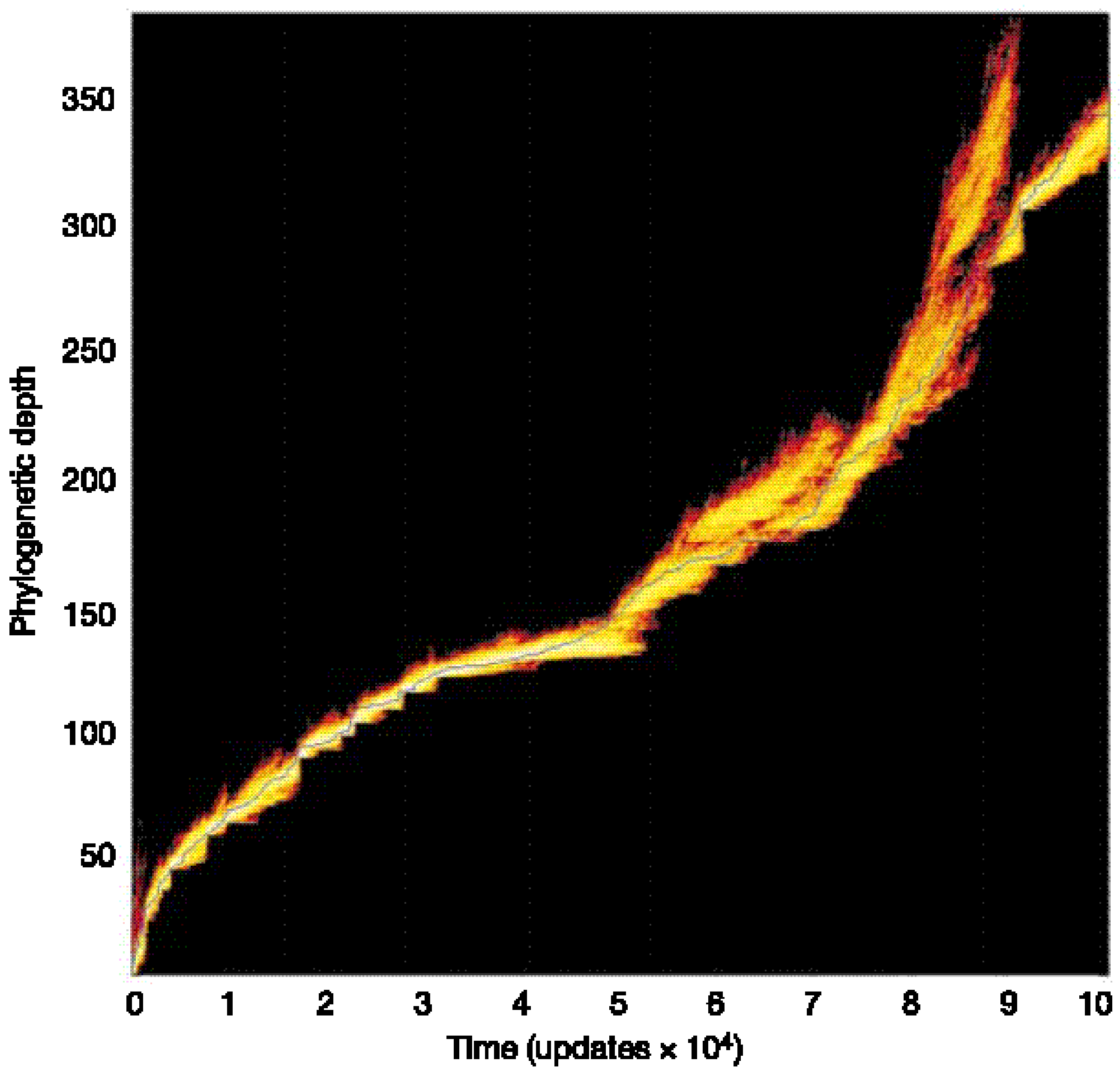

IO
sub
h-alloc
shift-l
swap
nand
nand
shift-r
nop-C
shift-l
nand
nop-A
IO
nop-A
nop-C
swap
nop-C
nand
if-less
pop
IO
add
swap
IO
X = 00010110...
Y = 10000100...
IN
AX: 01101101...
BX: 11010011...
CX: 10110110...
00001100...
11100111...
00111010...
00001100...
00000000...
00111010...
11011011...
00000000...
00000000...
OUT
01101101...
EQUI

Fitness

Energy occurs as quanta, called “single-instruction processing” units. Each organism receives SIPs in proportion to its genome length.

Table 1 **Rewards for performing nine one- and two-input logic functions**

Function name	Logic operation	Computational merit
NOT	~A; ~B	2
NAND	~(A and B)	2
AND	A and B	4
OR_N	(A or ~B); (~A or B)	4
OR	A or B	8
AND_N	(A and ~B); (~A and B)	8
NOR	~A and ~B	16
XOR	(A and ~B) or (~A and B)	16
EQU	(A and B) or (~A and ~B)	32


Phylogenetic depth
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
Time (updates × 10^4)

Results: EQU evolves

- ”there was a strong tendency for increased length to precede the origin of EQU” (p142) — *there is an explicit selection pressure on length*

- ”The presence of deleterious mutations along the line of descent is more surprising. Fifteen of the 18 deleterious mutations [...] might have hitch-hiked with beneficial mutations that arose soon after in the same genetic background” — *no reference to hitch-hiking theory in PG*

- “a mutation that was highly deleterious when it appeared was highly beneficial in combination with a subsequent mutation” — *how likely is it that populations in nature go through adaptive valleys? It depends on the representation.*

- ”The evolution of a complex feature, such as EQU, is not always an inexorably upward climb toward a fitness peak, but instead may involve sideways and even backward steps, some of which are important.” (p141) — *follows trivially from any ”fitness landscape” type consideration, although it is a point that unfortunately still needs to be made in discussions with some ”adaptationists”*

- ”Although the mutation of only one instruction produced this innovation when it originated, the EQU function evidently depends on many interacting components.” (p141) — *hardly a result of the simulations, because they already stated that when introducing the EQU function; i.e. it follows trivially from the problem definition*

- ”The actual paths [toward the EQU function in different simulations] were much longer and highly variable, indicating the circuitousness and unpredictability of evolution leading to this complex feature.” (p141)

- ”beneficial mutations that produced this new function usually, but not always, engendered trade-offs in other aspects of performance” (p142) – *valid points, but follow so trivially from the non-linear genotype–phenotype mapping (and the resulting pleiotropy & epistasis) and mutation scheme that we didn’t need these simulations to make these points.*

- “The consequences of asexual and sexual reproduction for the evolution of complex features deserves further research.”

Simulations & Artificial Life

1. Hinton & Nowlan (1987): How learning can guide evolution

2. Hillis (1990): co-evolving parasites

3. Karl Sims & Thomas Ray: evolution of locomotion strategies

4. Boerlijst & Hogeweg (1991): Spiral waves (spatial pattern formation)

5. Kirby (2000): Cultural evolution of language

6. Pagie & Hogeweg: evolution of population-based vs. individual-based resistance

7. Watson & Pollack (2000): How symbiosis guides evolution

Wolfram (1d cellular automata), Hogeweg & Hesper (social dominance hierarchies), Pollack (fractal encoding of grammar), Dorigo et al (ant algorithms).