reInstruct: Toward OS-aware CPU microcode reprogramming

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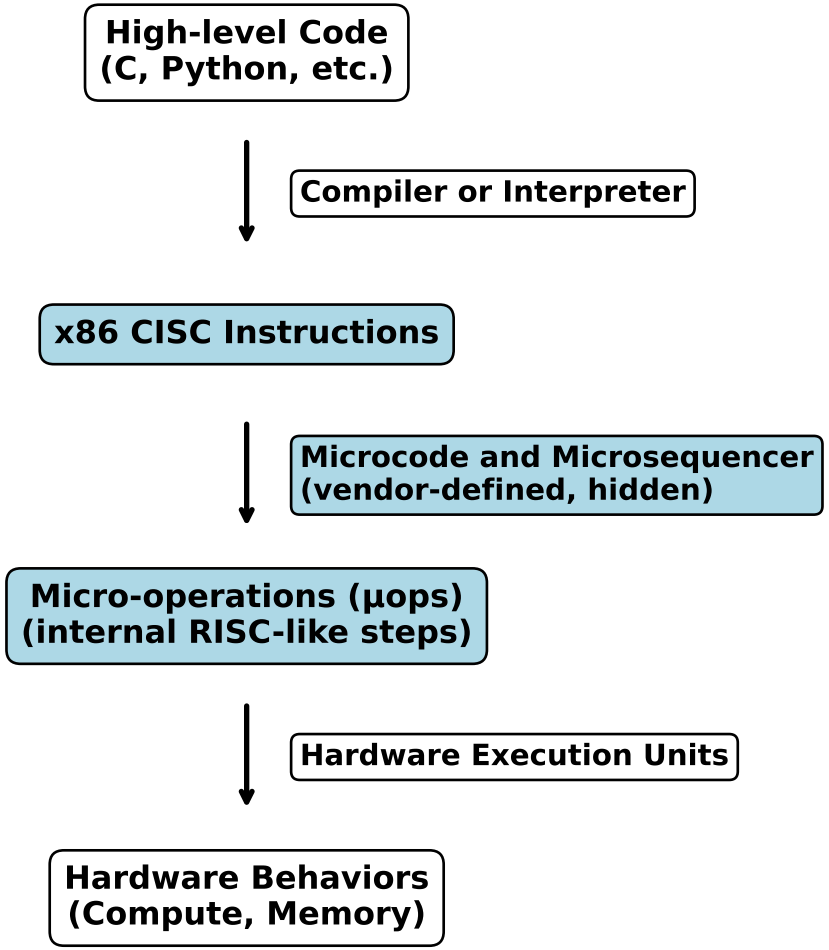
What is Microcode?



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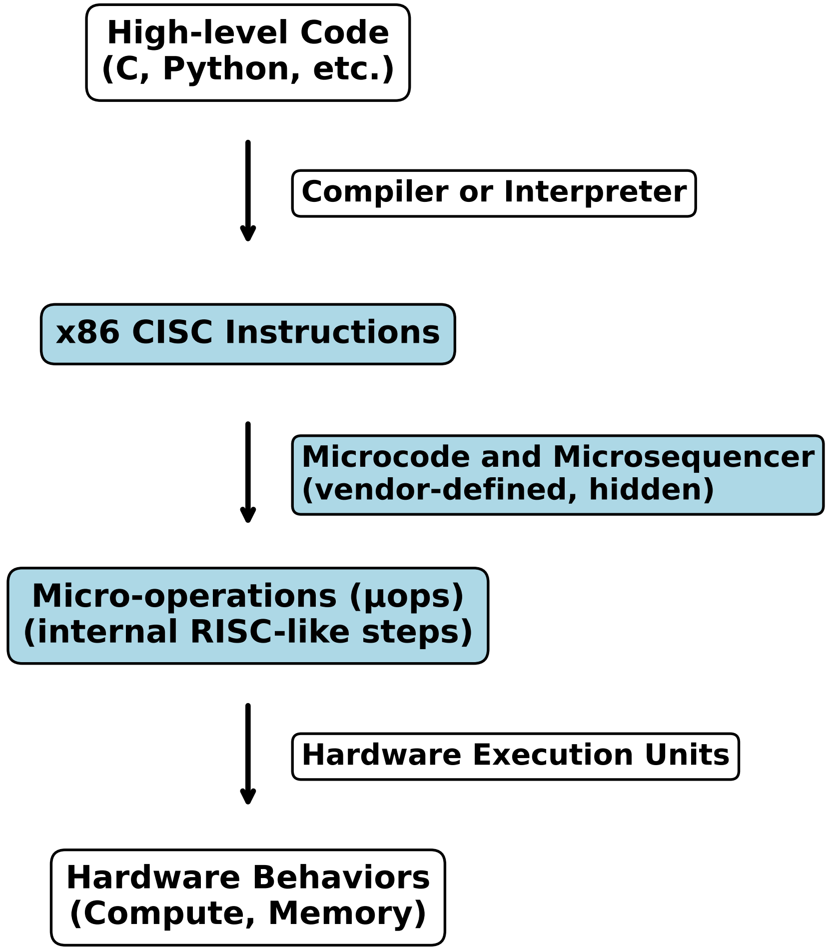

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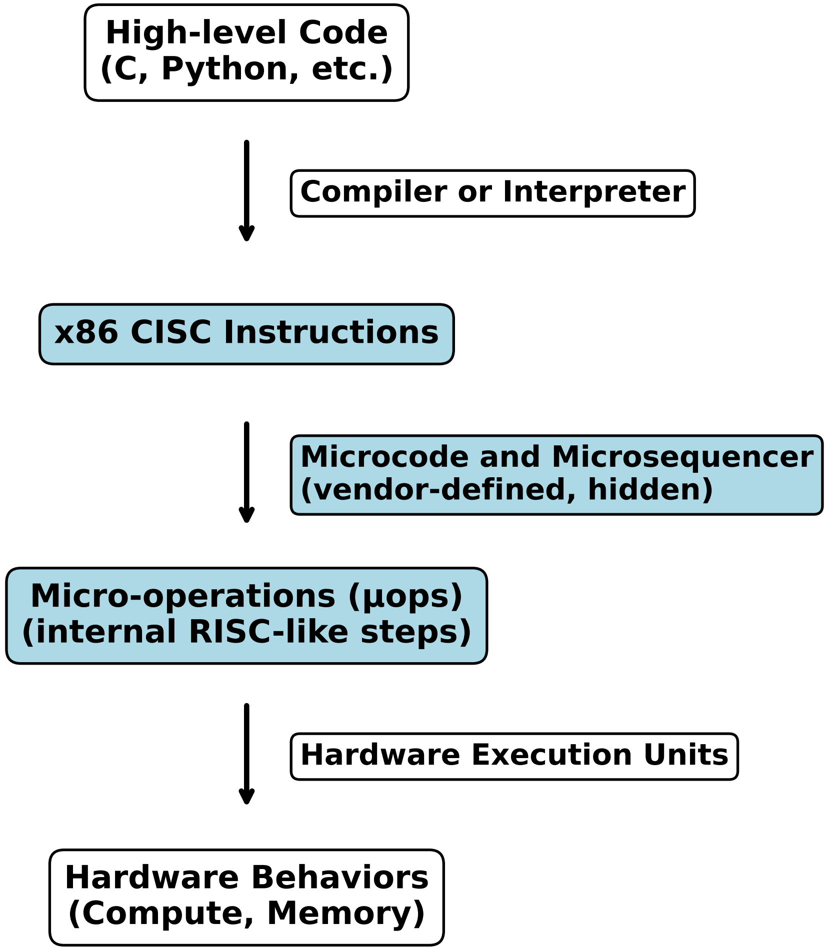
- Role: Works like firmware for the processor. **Defines** how each **instruction behaves**.



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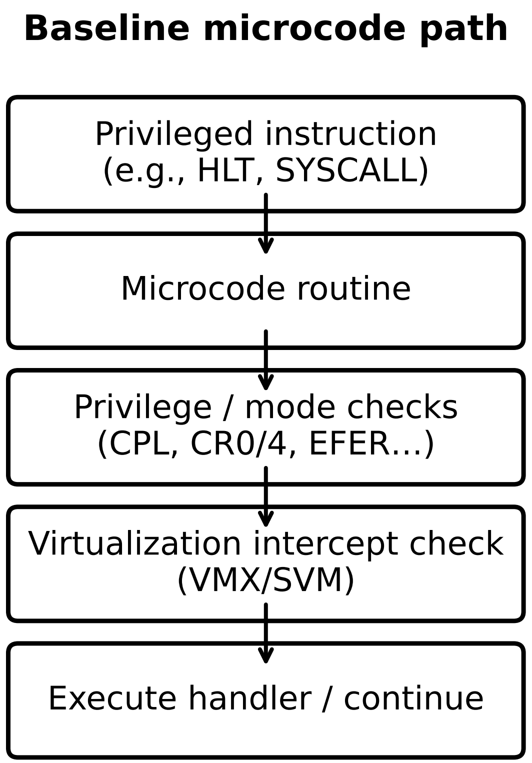

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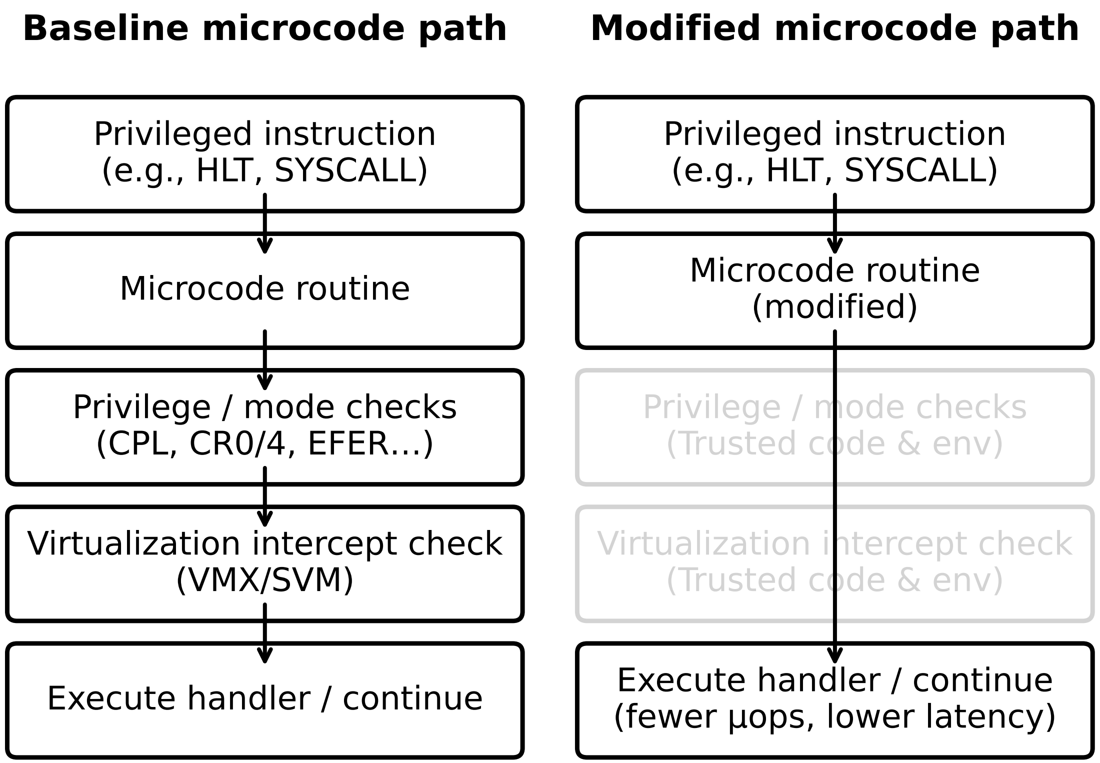

The Status Quo: Locked by Vendors 🔒

- Microcode is **proprietary**: no documentation, updates cryptographically signed, only distributed via vendor BIOS/OS channels.

- System software and researchers **cannot observe or modify** instruction behavior.

- So, the problem is, if we want to observe or modify the microcode layer, it is very difficult.

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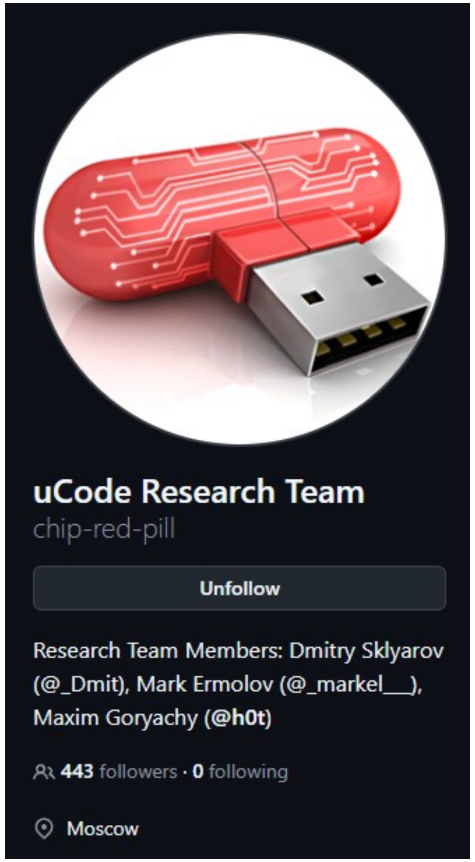

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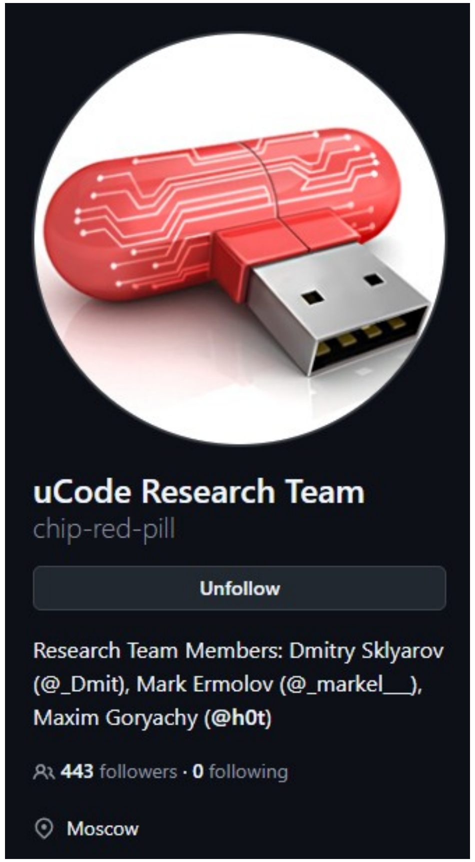

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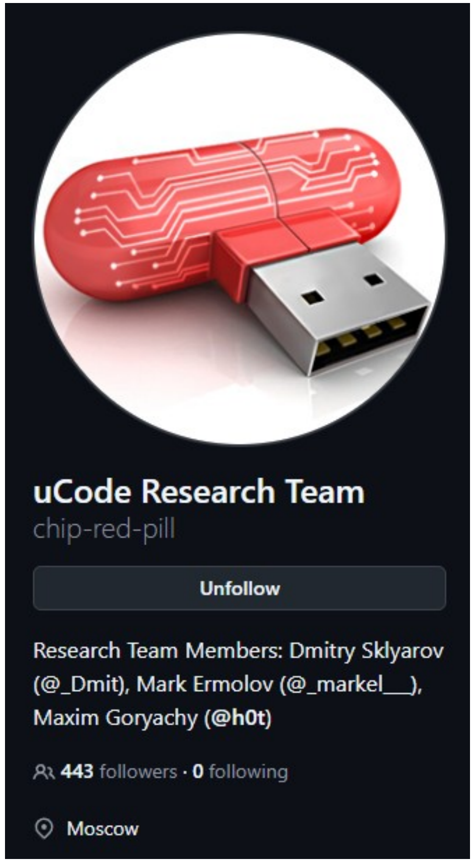

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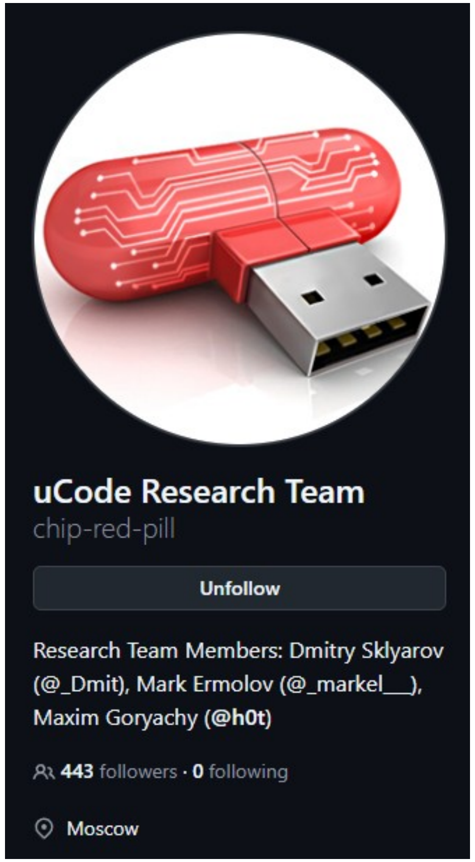
- **INTEL-SA-00086:** grants privilege escalation.
- **CHIP-RED-PILL** enabled a hidden "**Red Unlock**" mode to access CPU microcode internals.
- **CHIP-RED-PILL** revealed the vendor µop format and encodings, which made authoring custom microcode feasible.



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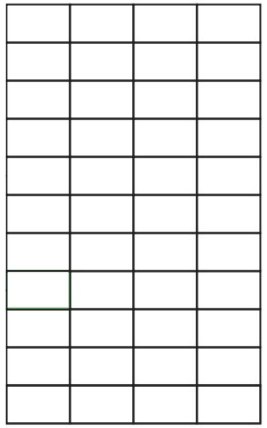

μcode ROM

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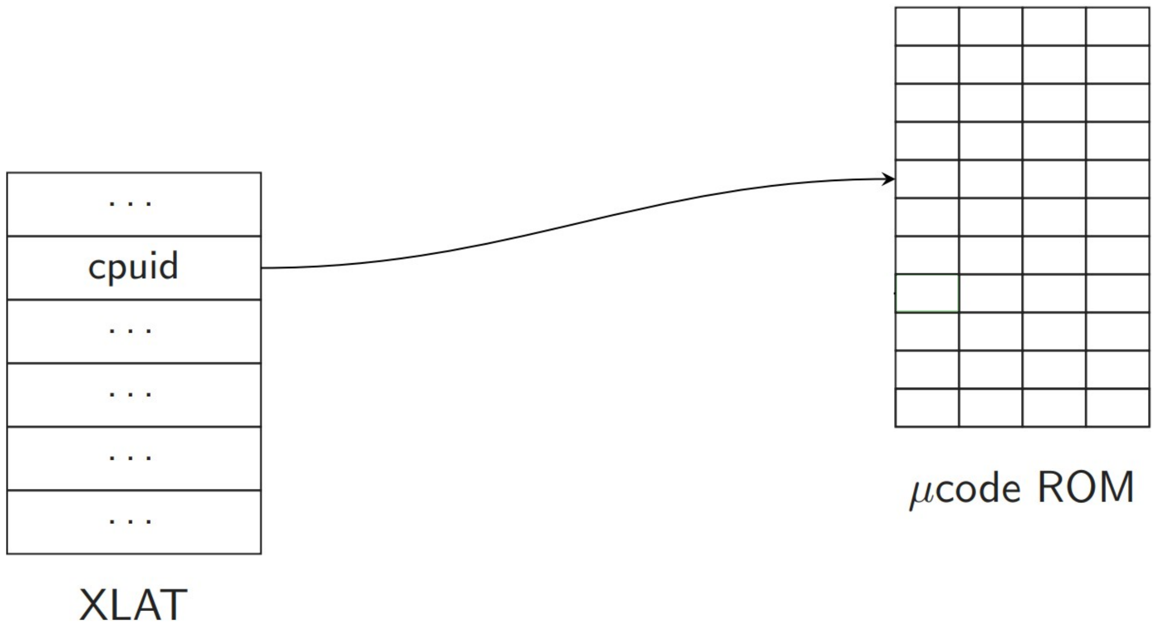

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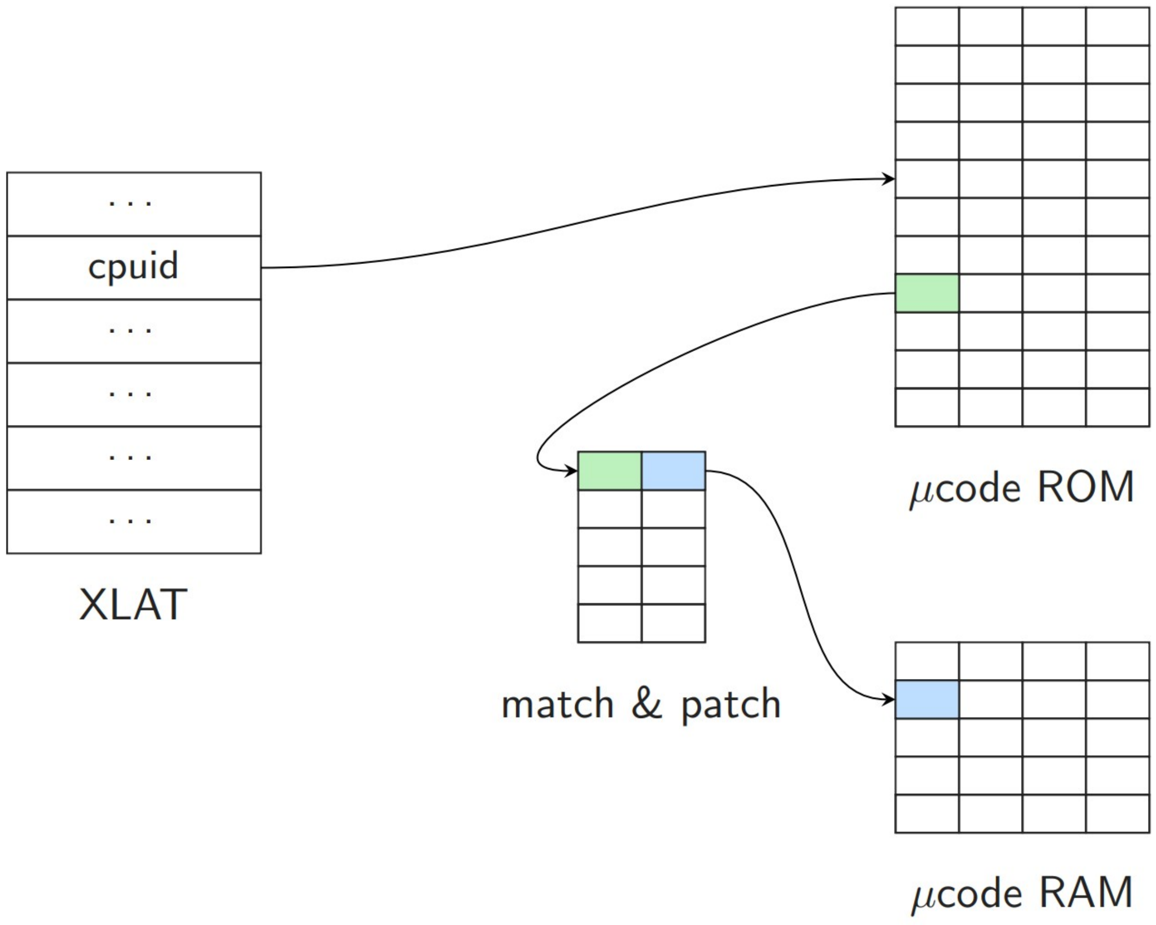

Prior Microcode Research Efforts

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These efforts proved that **microcode can be modified.**
But **not in a standard Linux runtime environment.**

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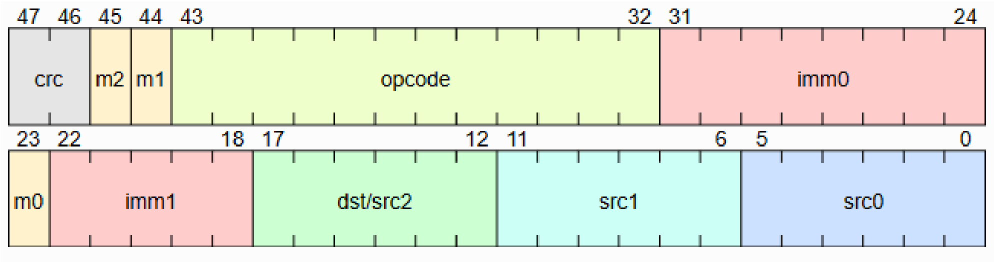
- We adopted **CustomProcessingUnit**'s microcode toolchain (DSL and assembler/serializer).

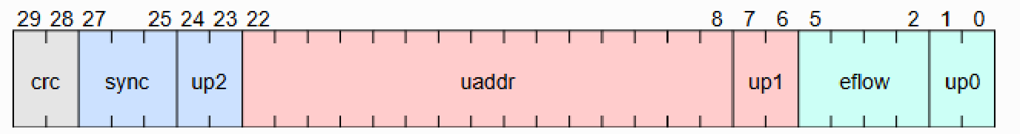
```
labuser@bmax-1:~/microcode-project/ucode_patches$ cat rdrand.u
.org 0x7c00
.patch 0x428
.entry 0

r64src := ZEROEXT_DSZ64(0x1146)
labuser@bmax-1:~/microcode-project/ucode_patches$ cat rdrand.h
struct ucode_patch_req rdrand_req = {
    .name = "rdrand",
    .addr = 0x7c00,
    .hook_address = 0x0428,
    .hook_entry = 0x00,
    .patch_rows = 1,
    .patch_data = {
        // U7c00: r64src := ZEROEXT_DSZ64(0x1146); unk_256() !m1; NOP SEQW LFNCEWAIT, UEND0
        {0x404846442008, 0x125600000000, 0x0, 0x130000f2},
    }
};
```

µop:



Seqword:



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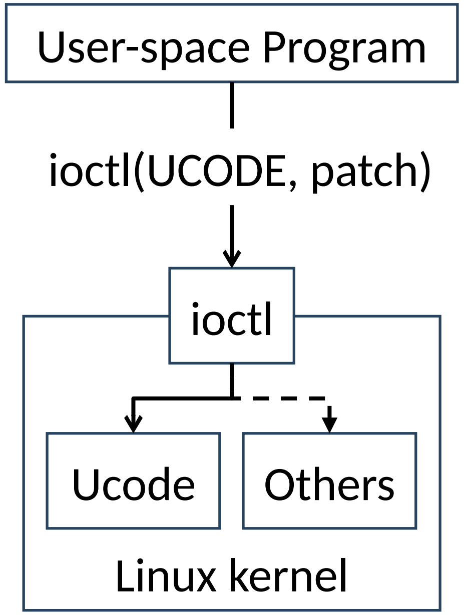

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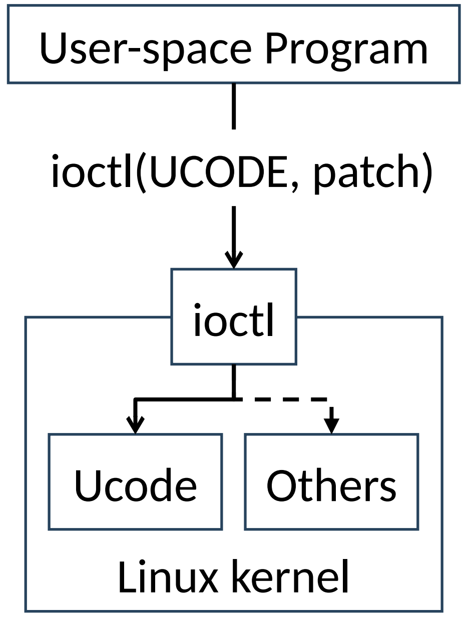

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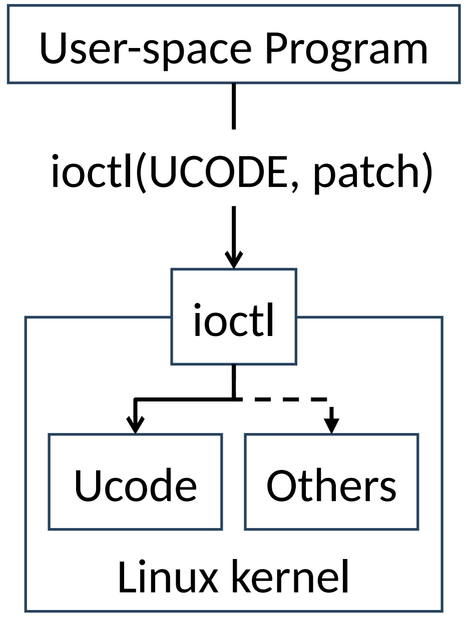
  - Accepts and applies custom microcode patches.



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#define rd(addr) ({ \
    unsigned long long __res; \
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        "rdrand %%rbx\n" \
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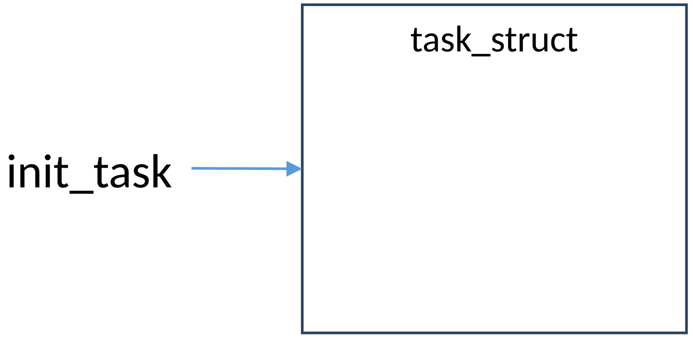

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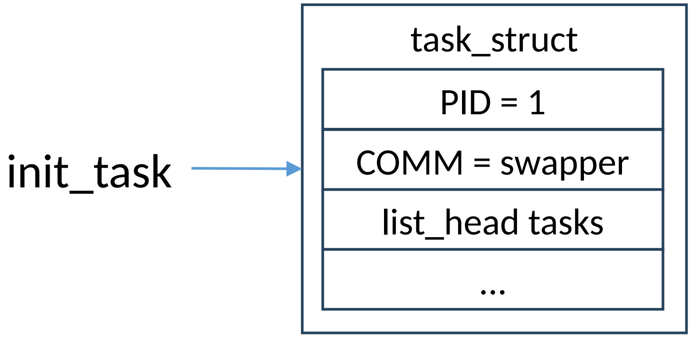
  - Locate the symbol init_task, which gives us the address of the first task_struct.
  - Once a task_struct is found, we can **extract fields by their known offsets:**
    - For example, to read the process name: comm = *(task_addr + comm_offset)



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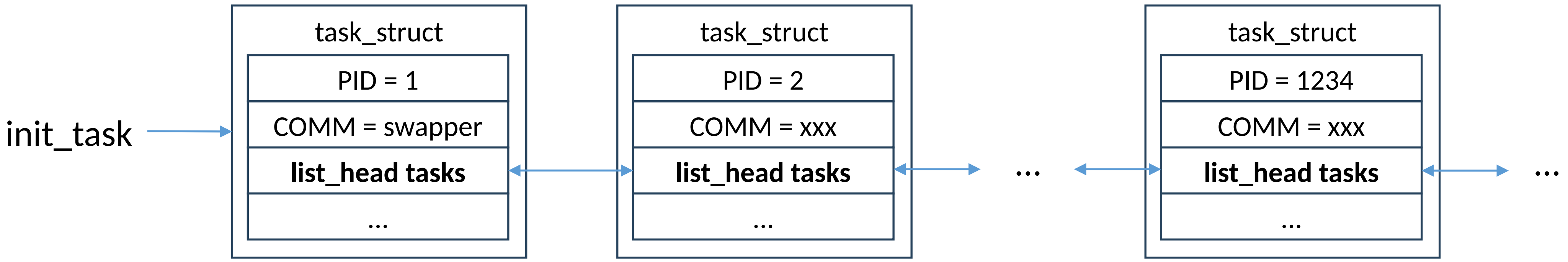

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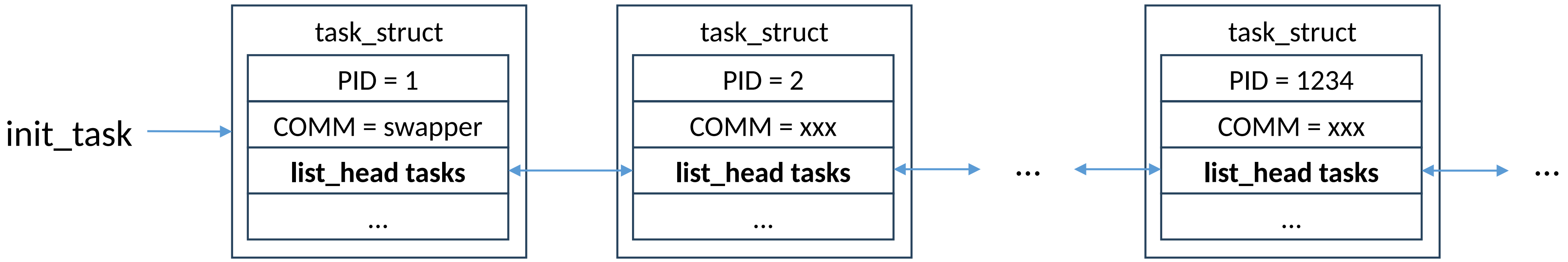

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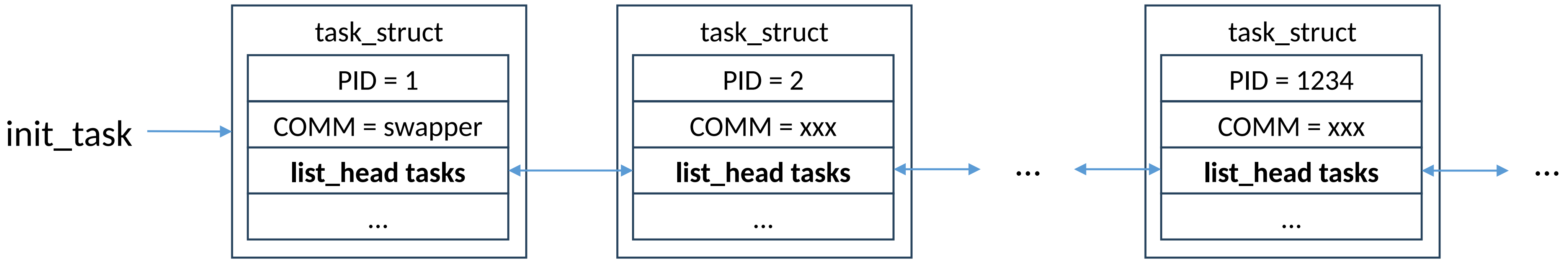

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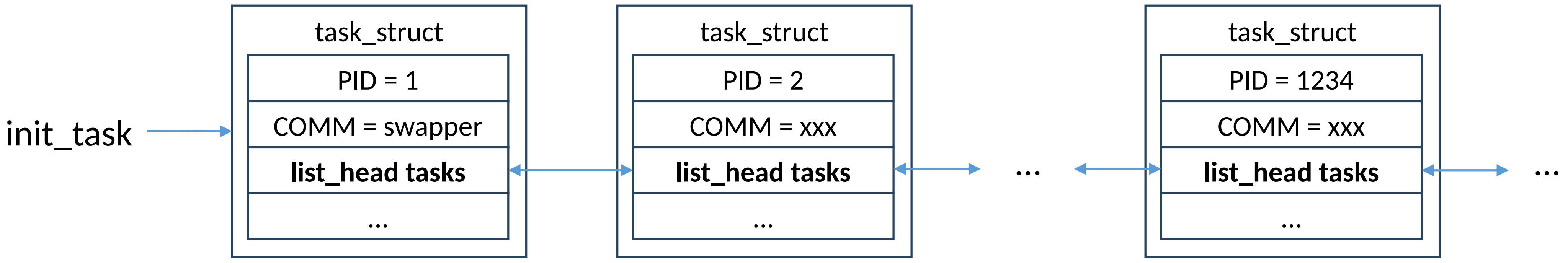

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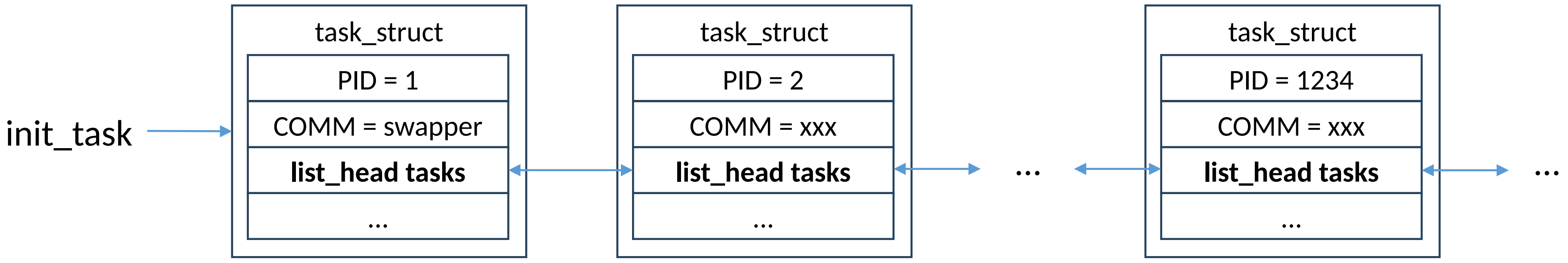

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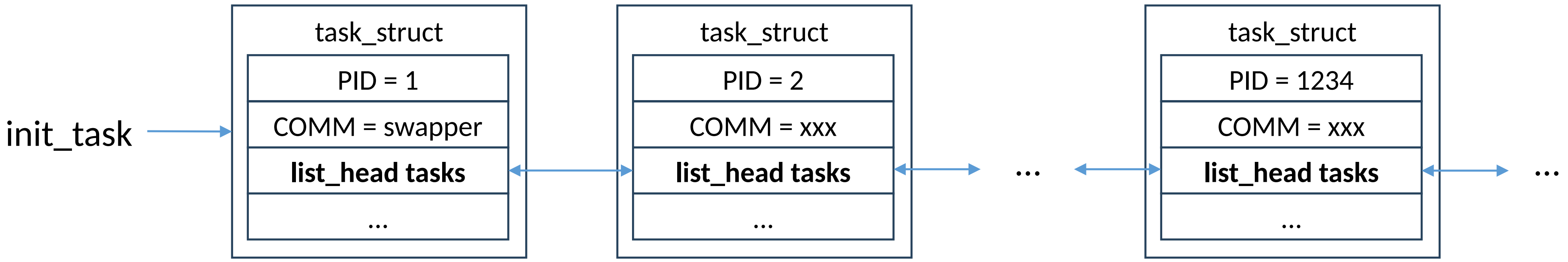

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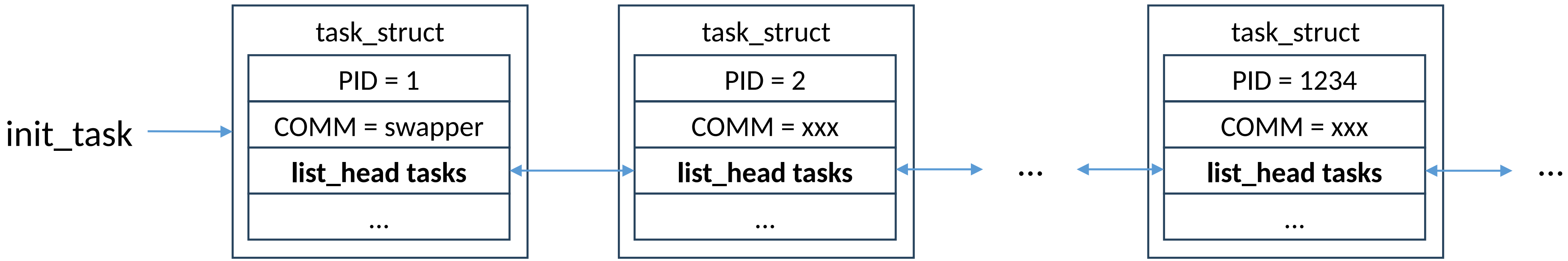

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gcc test_read_tasks.c -o test_read_tasks.o
./test_read_tasks.o
Patch applied successfully!
== init_task ==
Task @ 0xffffffffab010940: PID = 0, COMM = swapper/0

== Iterating through all task_struct ==
Task @ 0xffff974e402a3200: PID = 1, COMM = systemd
Task @ 0xffff974e402a0000: PID = 2, COMM = kthreadd
Task @ 0xffff974e402a6400: PID = 3, COMM = pool_workqueue_
Task @ 0xffff974e402a1900: PID = 4, COMM = kworker/R-rcu_g
Task @ 0xffff974e402a4b00: PID = 5, COMM = kworker/R-sync_
Task @ 0xffff974e4032b200: PID = 6, COMM = kworker/R-slub_
Task @ 0xffff974e40328000: PID = 7, COMM = kworker/R-netns
Task @ 0xffff974e40330000: PID = 11, COMM = kworker/u8:0
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Task @ 0xffff974e40333200: PID = 15, COMM = rcu_tasks_trace
Task @ 0xffff974e4033e400: PID = 16, COMM = ksoftirqd/0
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  - Read the password from the buffer.

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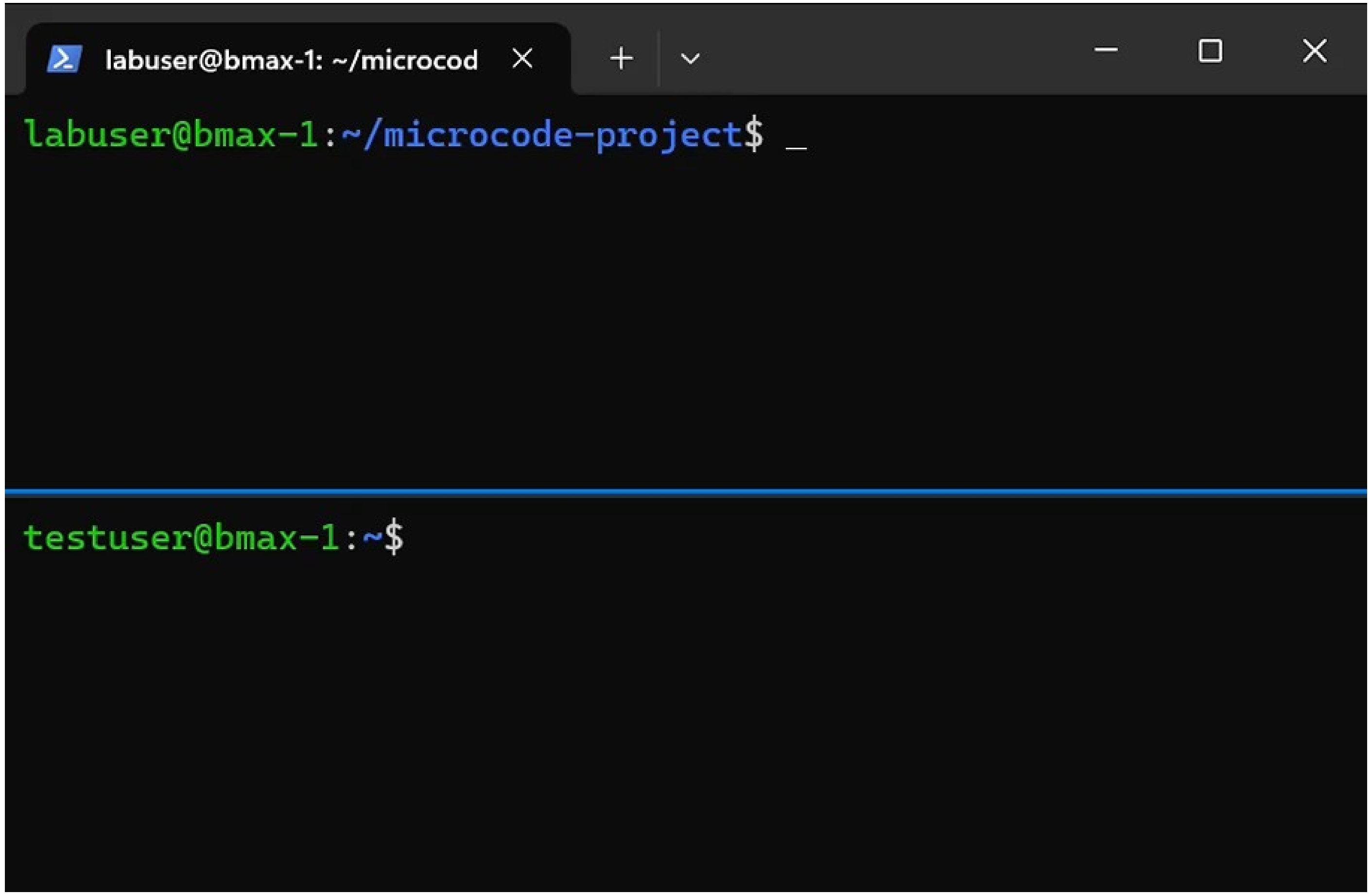

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- User program executes RDRAND → immediate core ID returned (no syscall, no kernel transition).

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  Build a microcode framework that supports **per-core** and **per-thread** customization, integrates with the Linux kernel, and provides easier user-space access.
- **AMD Support**
  Port and test on AMD Zen CPUs to explore cross-vendor compatibility and new customization opportunities.

Q & A

Thank you!

This work is supported in part by the US Office of Naval Research (ONR) under grant N000142412642.