Deterministic Behaviours are your Attacker's Friend

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Outline

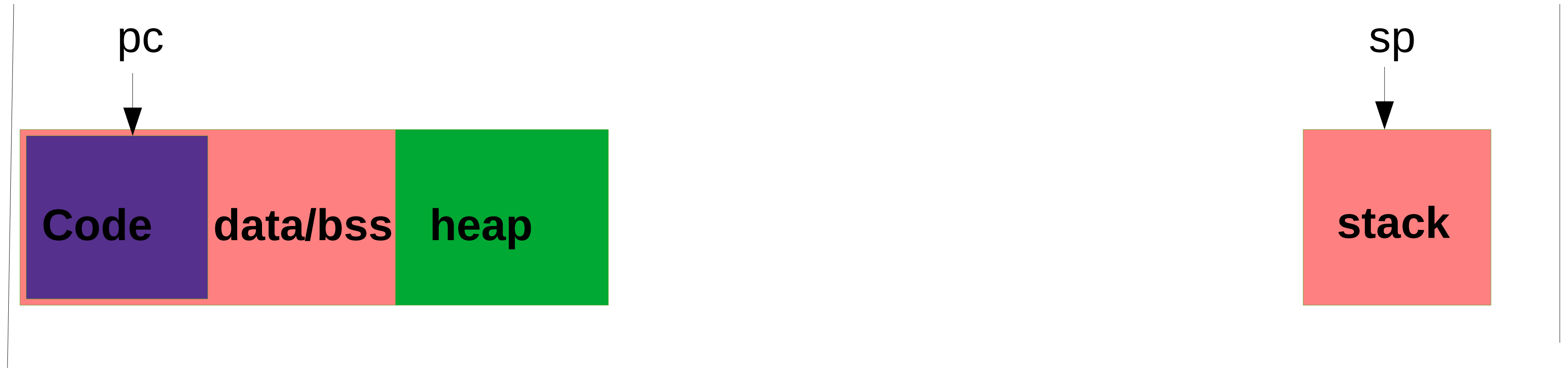
- The Moment of Failure
- Memory/Register state at moment of Failure
- What attackers do with this
- What can be done about it?

Oops, a bug is triggered by unexpected data

- Programmer mishandles some situation, and things go off the rails
  - Generally, code keeps running for a quite a while
  - Reading this, writing that, etc
  - Until it performs an illegal operation
  - SIGSEGV/SIGBUS, etc
- Attacker observes this condition
- Fuzzing is making it easier to find such bugs

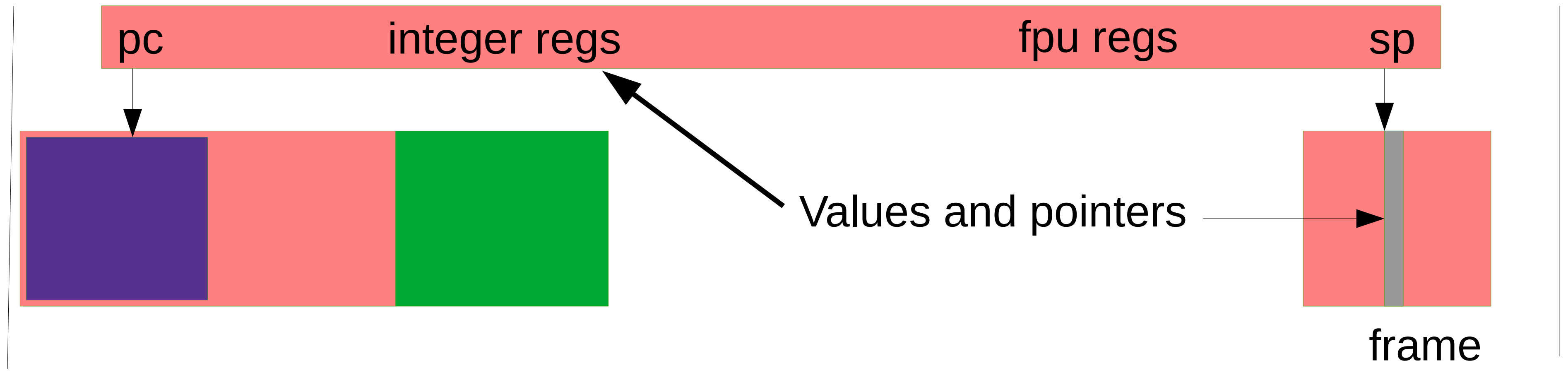
What does it actually look like

- Static binary memory layout



What does it actually look like

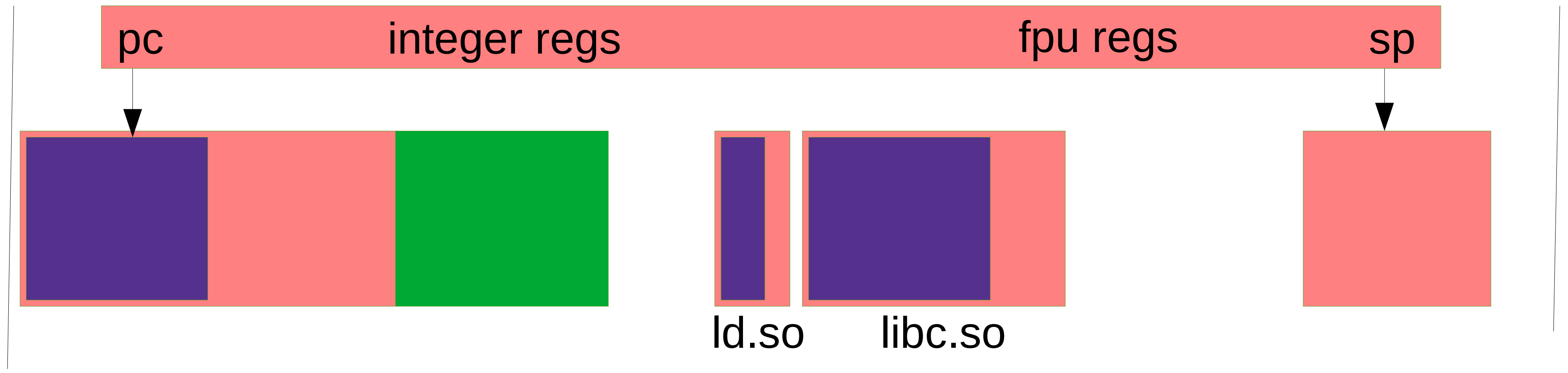
- The Crash state



- Before 1999, every crash state had an identical footprint

What does it actually look like

- Dynamic binary



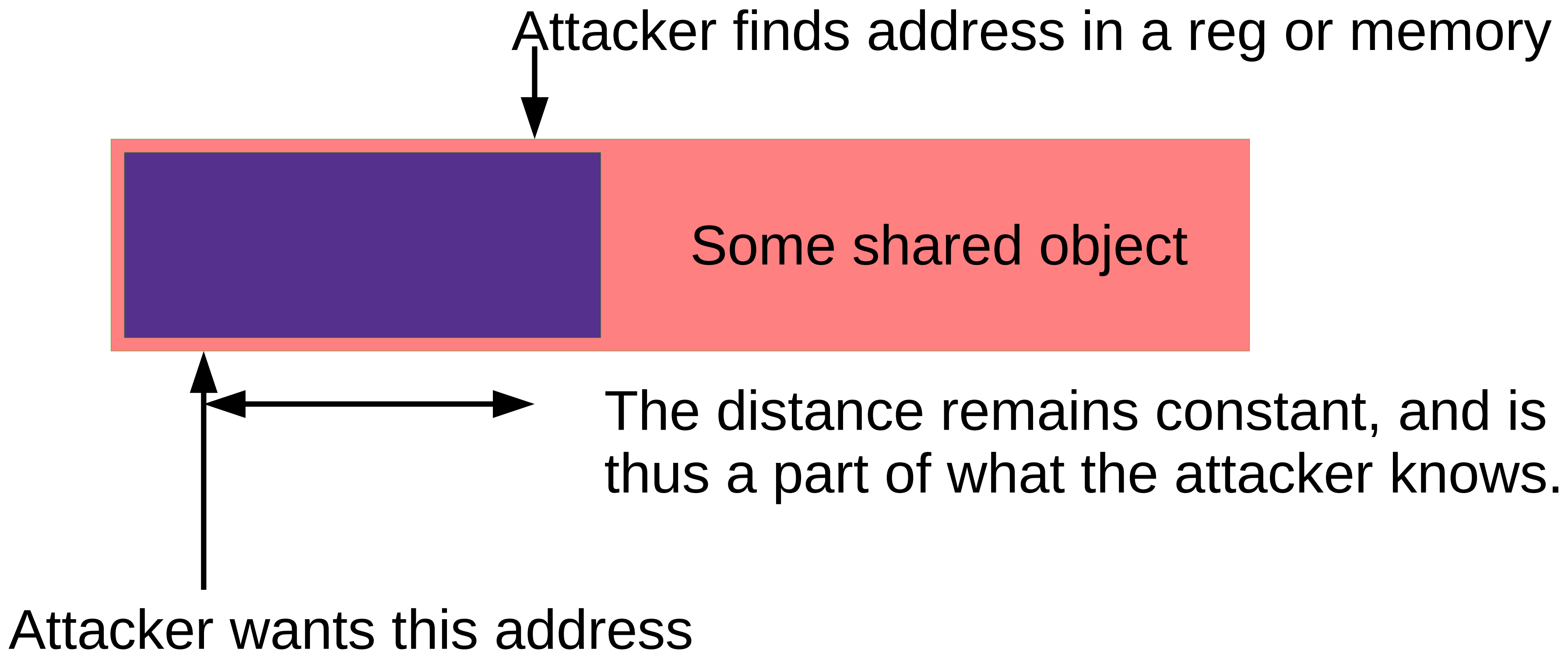
- Just more state. PIC code model

What the attacker knows

- In 1999
  - Crash-State 100% identical on attacker‘s test host and target host
  - Attack method could be iterated till perfection
  - Then deliver payload, own the target

- By 2010, ASR+W^X+stack-protector had added many unknowns and increased difficulty for the attacker

Consider Constant-Relative offsets


Attacker finds address in a reg or memory
Some shared object
The distance remains constant, and is thus a part of what the attacker knows.
Attacker wants this address

What the attacker does

- Before 1999, classic buffer overflows were the common technique
- After W^X became common, ROP methodology became more common
- With ASR/ASLR now common, sprays and other non-turing-complete "damage the state“ methods become common.
- In JIT systems, the stack protector is usually absent.

What can be done about this?

REMOVE INFORMATION & INCREASE CHANCE OF SIDE-EFFECT DAMAGE

- Perturb address spaces
- Strict permissions (RWX, X-only, MAP_STACK, syscall-notX)
- Micro-architectural random cookies (stackghost, SROP)
- Self-protecting data structures (malloc, setjmp)
- Stackprotector / RETGUARD
- PIE, bindnow, ld.so unmapping
- Guards and trapsleds

Perturb address spaces

- PIC to PIE
- Kernel and ld.so do random layout
- All heap allocations via random mmap()
- ASR (not ASLR)

- libc/libcrypto/ld.so boot-time randomization
- KARL kernel boot-time randomization
- amd64 & arm64 VA+PA KASRL

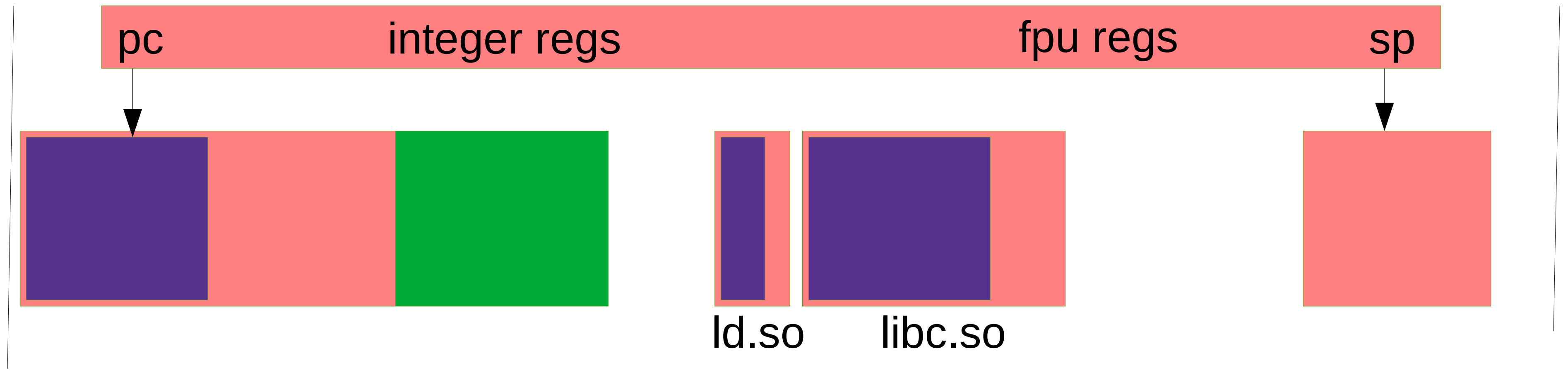
Allocation guards and code trapsleds

- Guards are unmapped memory between objects
- More guards $\rightarrow$ improved chance an attacker‘s misfire kills him

- Trapsleds are illegal instructions in the instruction sequence, rather than the classic NOP sequences used in the past (for various reasons)
- Requires an attacker to precisely target gadgets, rather than sliding through NOPs
- (Used heavily in the RETGUARD design)

Perturbances - Before

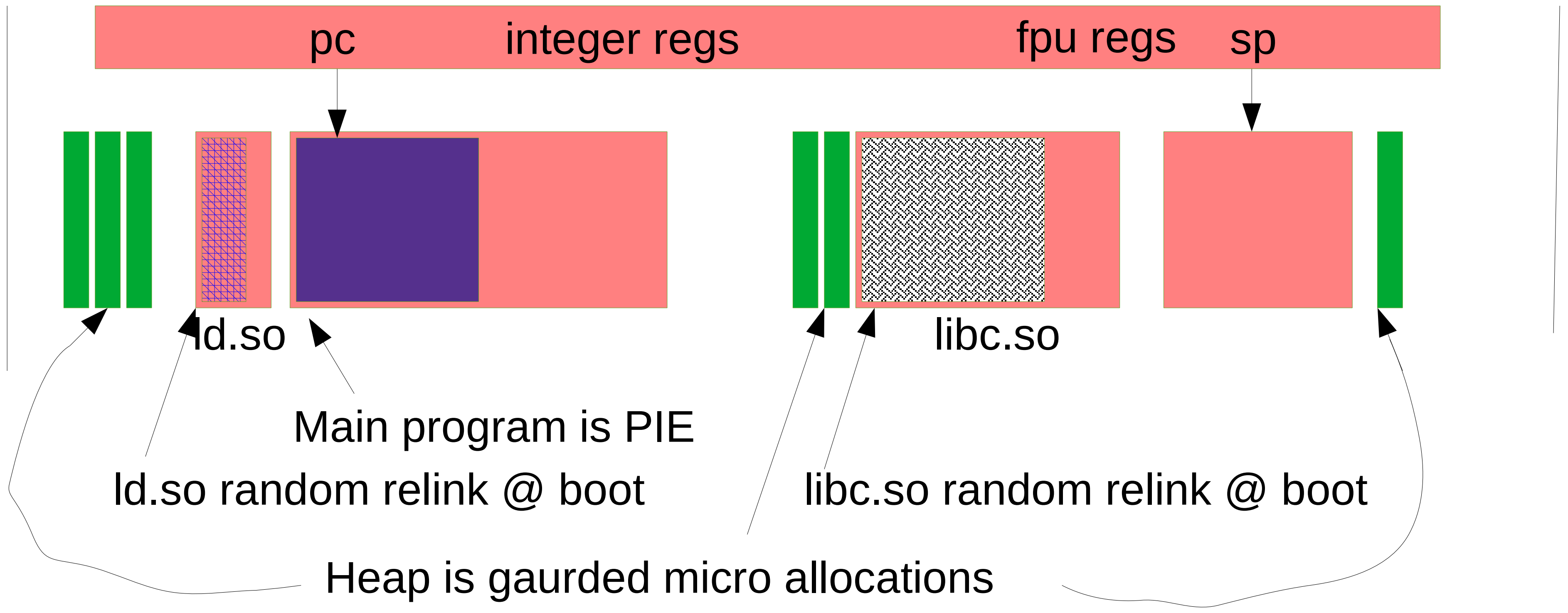
- Dynamic binary



- Just more state. PIC code model, and maybe PIE

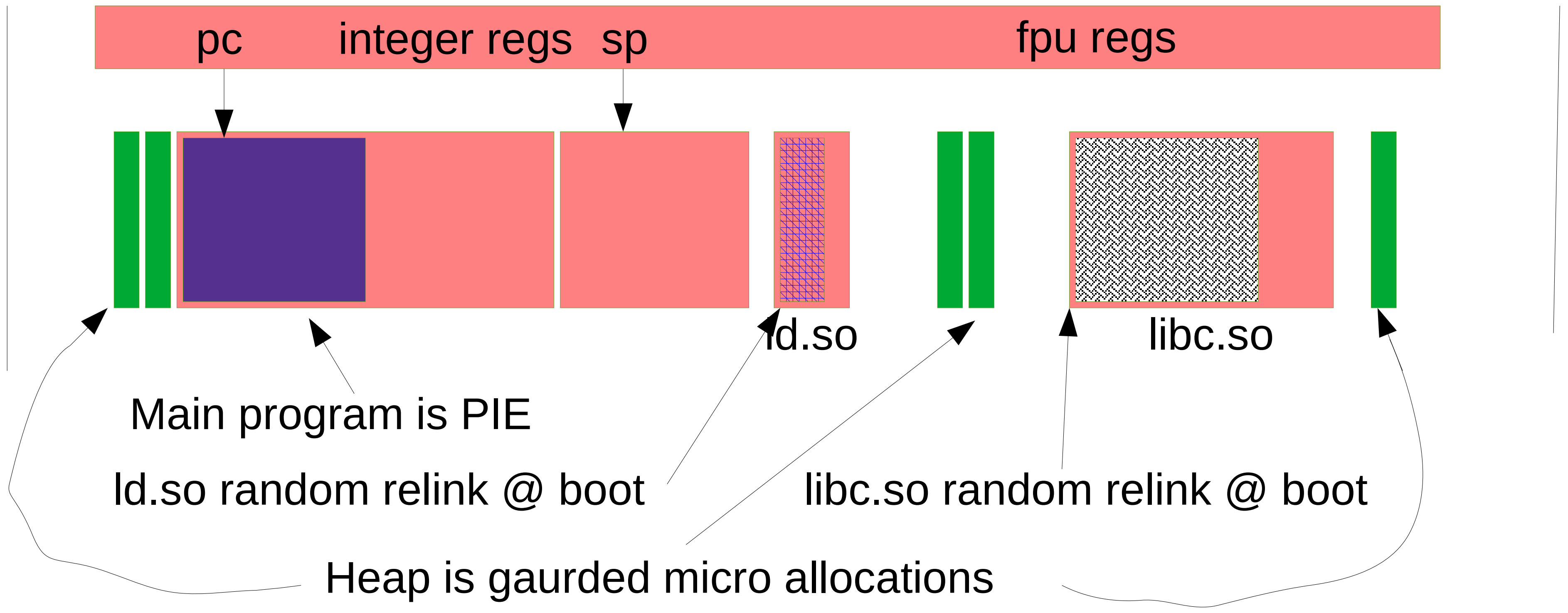
Perturbances – After

All objects random placement


pc
integer regs
fpu regs
sp
ld.so
libc.so
Main program is PIE
ld.so random relink @ boot
libc.so random relink @ boot
Heap is gaurded micro allocations

Perturbances – After (2nd run)

All objects random placement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There are still some knowns

- At moment of crashing
  - A specific register will still have a constant value
  - Pointers will still point at the same objects
- But many relative offsets are disrupted
- libc.so and ld.so boot-time randomization helps
- Cannot use part of a pointer as a integer constant in a calculation
- ROP gadgets & their locations are not known

Strict page permissions

- W^X
- .rodata
- Trying to develop X-only (to prevent blind ROP)
- MAP_STACK pseudo page-protection (prevents ROP-stack pivot into data memory)
- syscalls not permitted from writeable memory

History of our Stack-Protector

- 2001 – stack-protector protects functions >= 16 bytes of local
- 2012 – one stack-protector value per shared-object
- 2014 – stack-protector-strong (more functions protected)
- 2015 – stack-protector values become read-only
- 2018 – RETGUARD: unique read-only stack-protector value per function (all functions protected to eliminate terminator-gadget)

Micro-architectural cookies

- Stackghost (sparc64)
- SROP mitigation (cookie in sigcontext)
- setjmp/longjmp cookie

Self-protecting data structures

- atexit() chain storage is write-protected
- malloc() tracking datastructures are out-of-band
- Large number of paranoia features in malloc() and free()

Remove ROP gadgets

- SROP eliminated
- RETGUARD
- OpenBSD/arm64 has no RET-ROP gadgets!
- X86 instr Polymorphic RETs can be significantly reduced (nearly eliminated)
- ld.so unmapping when finished (dlopen gadgetry)
- crt0 gadgetry cleanup

The role of privsep, fork + exec

- Privsep: Rewrite programs and structure them in a micro-kernel way

- Fork+exec: create new & unique address spaces whenever possible

- Moment-of-Failure knowledge from one privsep process, isn‘t applicable in another privsep process

Complexity, Cost, Tradeoffs

- Cost of change must be evaluated

- As machines get faster, it is reasonable to use a larger portion of the cpu for self-protection

Pledge and unveil

- If the attacker manages to execute code in your environment
  - Take away as many system calls as possible
  - Restrict the filesystem space available

Conclusions

- Situation is much improved since 1999
- A Full-Stack approach
- Many other systems matching our trajectory
- Open-ended mission: More interesting work to do.