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ROPecker
A Generic and Practical Approach For Defending Against ROP Attacks

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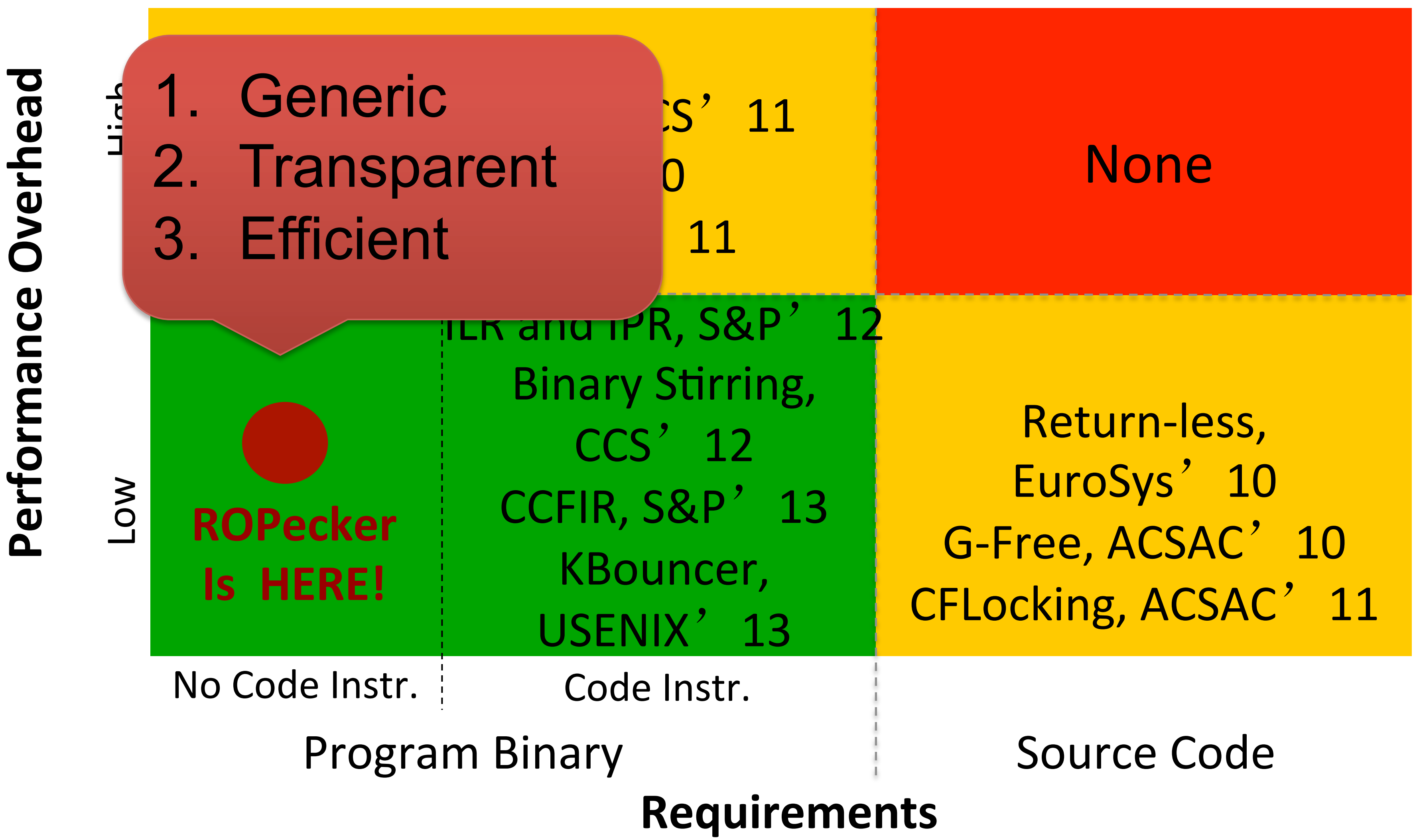
Return-Oriented Programming

- ROP attack is a code-reuse attack
  - No injected malicious code
- To launch an ROP attack
  - Identify intended gadgets
    - End with indirect branches, e.g., ret, jmp, call
    - Small size
    - Sparsely distributed -> (imply) needing large code base
  - Chain identified gadgets

Existing Approaches



Assumptions

- DEP mechanism is enabled
  - NO attempt to protect self-modified applications
- ROP gadgets are sparsely distributed
  - Need large code base for collecting intended gadgets

- NOT rely on ASLR mechanism
- NOT rely on side information

Design Rationale

- Evidence of ROP Attack
  - Reliable - adversary can not modify them to evade detection
  - Sound – solid evidence

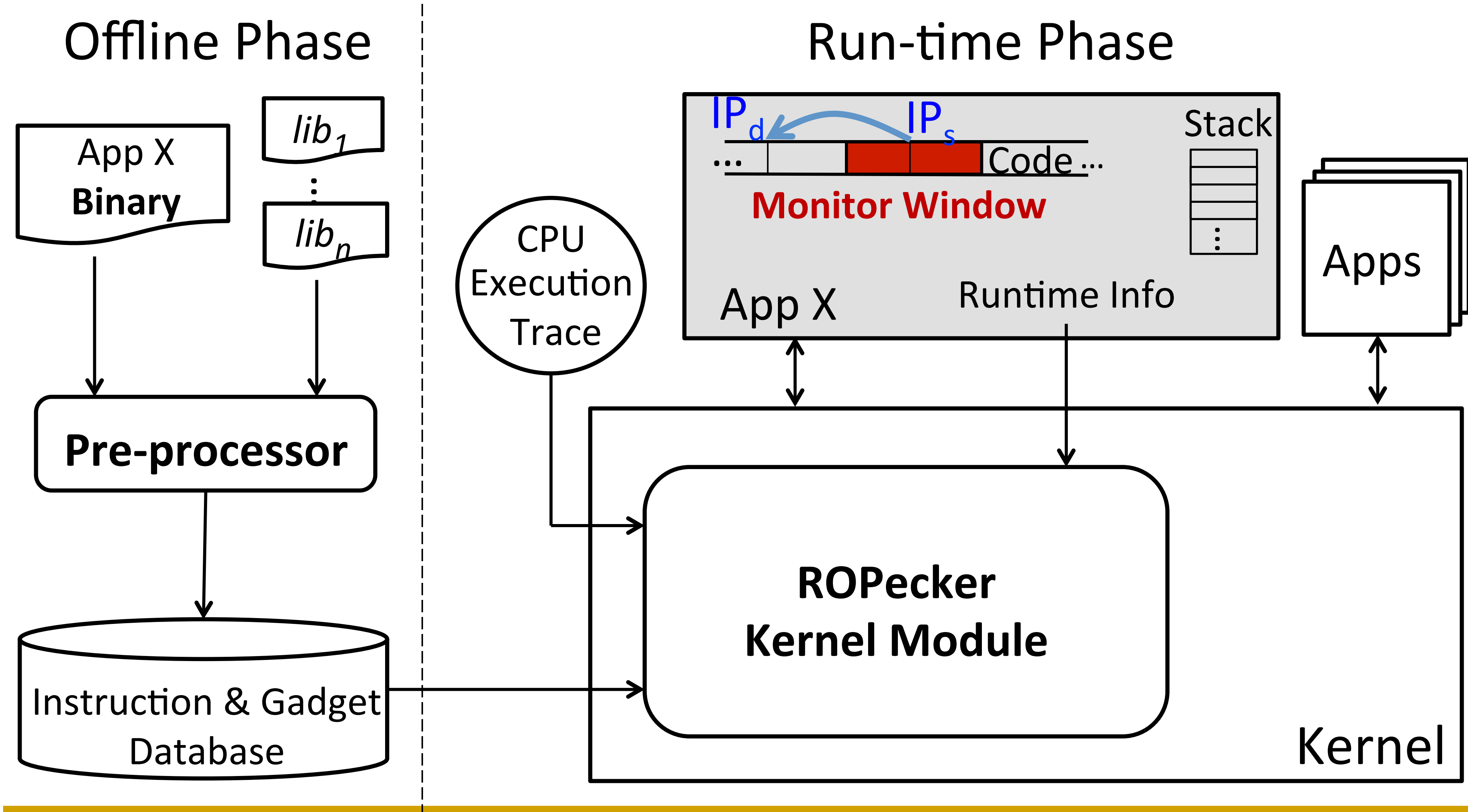
- Timing of detection
  - Event driven (NOT busy monitoring)
  - Non-bypassable

Design Overview

- Reliable and Solid evidence - ROP gadget chain
  - Last Branch Record (LBR)
  - Runtime execution flow

- Timing of checking
  - When the execution flow jumps out of the sliding window

ROPecker Architecture



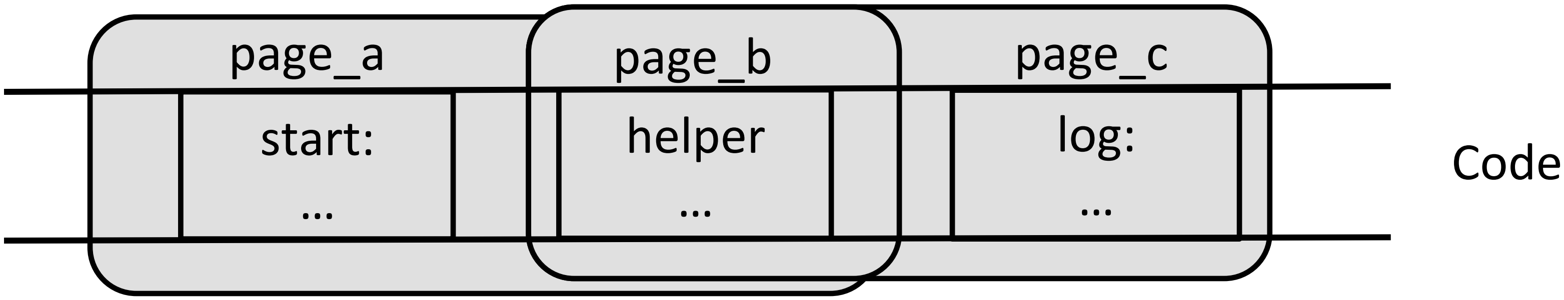
Offline Pre-processing

- Instruction Disassembling
  - Reliable
    - Only disassemble 6 instructions in a time (not the whole application)
  - Efficient
    - Only do once for each application/library
- Extracted instruction information is saved in database
  - Save runtime cost

Sliding Window

- Refers to a small portion of code pages
  - Only code pages within the window are executable
- Non-bypassable
  - No enough gadgets within the window for ROP attackers
- Efficient
  - Temporal and spatial locality feature - sliding window could be ***non-contiguous*** code pages

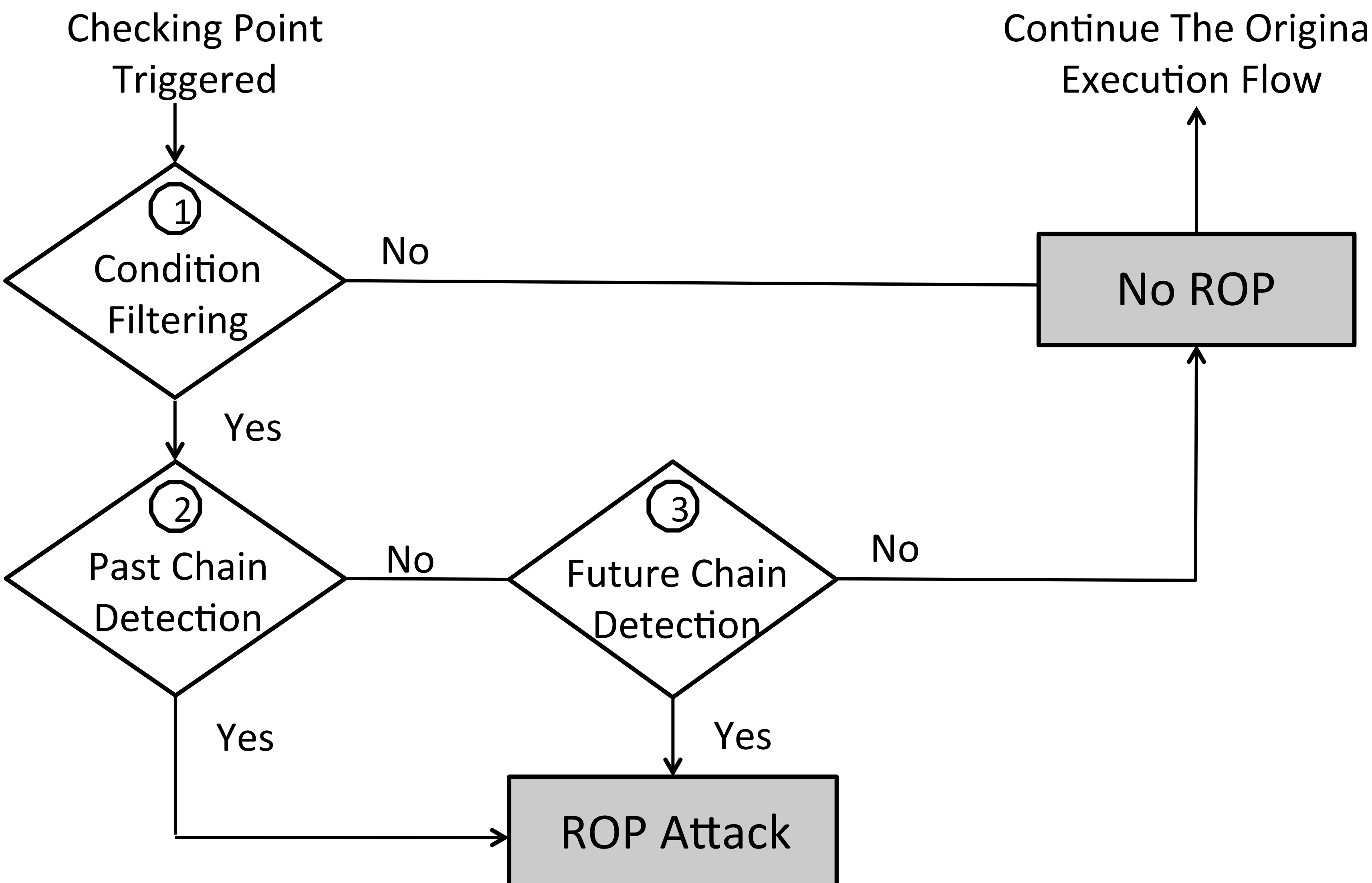
Sliding Window Update



Sliding window has 2 code pages

```
int helper(int cmd,char* in){
   log(cmd, in);
   switch(cmd){
        case CMD_START:
            start(inputs);
            break;
        . . .
}
```

Detection Algorithm



Condition Filtering

- ROPecker is able to distinguish the exceptions triggered by the sliding window from others
  - PID
  - Error code

Error code bits
Present bit
Read/write bit
User/supervisor bit
Reserved bit
NX bit

```
Error code triggered by
sliding window is 0x15
```

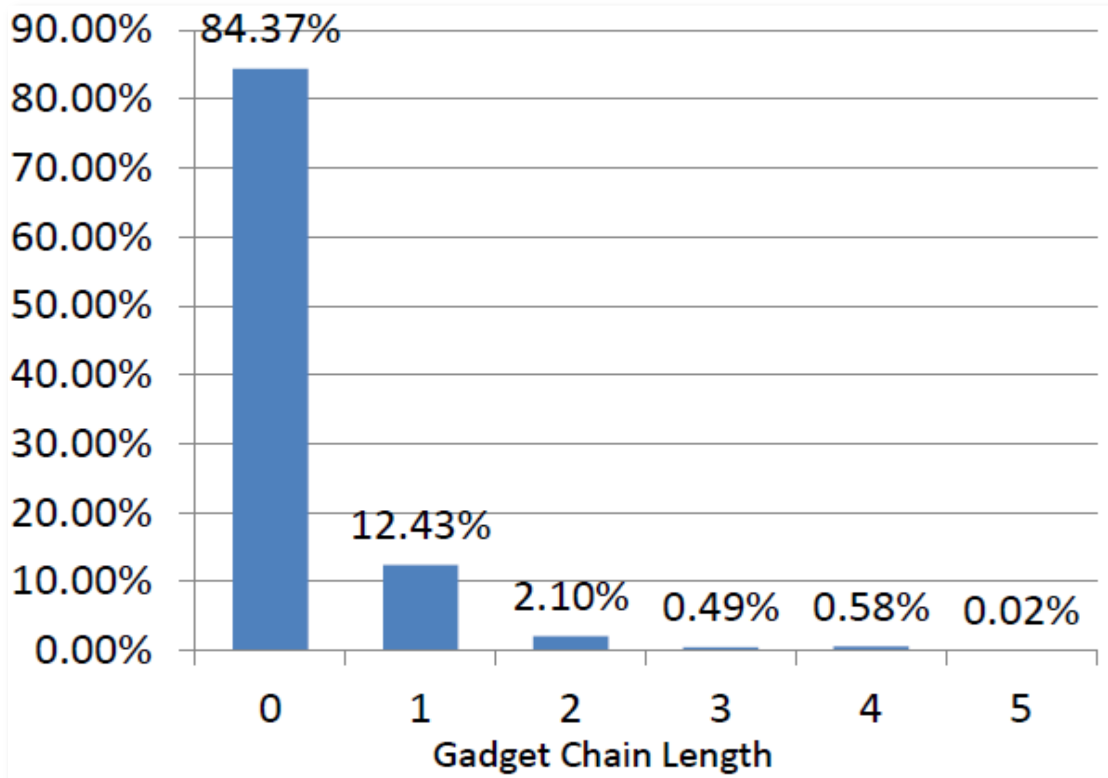
```
All other error codes
are not 0x15 in the
normal executions
```

Past and Future Chain Detection

- Past execution traces in LBR
  - LBR number is limited, e.g., 16 records
  - Filter out noise records
- Future gadget chain
  - Directly calculate using (offline) generated database
    - Reduce emulation times
  - Seldom triggered Runtime emulation
    - Low performance overhead

Discussions

- Gadget chain threshold
  - The threshold is small, e.g., 5 for Apache
  - Performance degradation is limited
- Stack pivoting
  - ROPecker (kernel) is able to know the position of stack



Implementation and Evaluation

- Implemented on Linux (Ubuntu 12.04 with kernel 3.2.0-29-general-pae)
- New tools for offline processor
  - *diStorm + Perl + objdump + readelf*
- Kernel module consists of *7K* SLOC
  - Runtime emulator (from Xen) is *4.4K SLOC*
  - Use NX mechanism for sliding window creation
  - Modify IDT for page fault interception

Space Evaluation

- The databases for all ***2393*** shared libraries under */lib* and */usr/lib* of the Ubuntu Linux 12.04 distribution is about ***210MB***
  - On average, the database of each lib is ***90KB***
  - Compressed to about ***19MB*** using ***bzip2***

- Each database only has one copy in memory
  - e.g., all protected processes share one ***libc*** database

Performance Evaluation

- Micro-benchmark
  - Past gadget chain detection – *0.07μs*
  - Future gadget chain detection – *0.91μs* (w/o emulation), *2.61μs* (with emulation)
- Macro-benchmark
  - SPEC INT2006 - *2.60%* overhead on average
  - Bonnie++ - *1.56%* overhead
  - Apache - *0.08%* overhead on typical (*4KB*) HTTP communications

Limitations

- Short gadget chain
  - e.g., one-gadget ROP attack

- Long gadgets
  - e.g., a gadget with 20 instructions
- **Gadget Gluing Attack**

  - Constructing a special gadget which consists of two short code sequences glued together by a **direct** branch instruction

Conclusions

- ROPecker
  - Efficiently, transparently and effectively defend against ROP attacks
  - Without relying on any other side information or binary instrumentation.
  - Small space and performance cost

- Code is available, please contact with strongerwill@gmail.com


Thanks
Questions?
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