UNIVERSITY OF CALIFORNIA
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Unveiling your keystrokes: A Cache-based Side-channel Attack on Graphics Libraries

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Introduction

- Graphics is essential
- Graphic rendering is complex
  - gdk, gtk, pixman, freetype, cairo, skia, hwui, …

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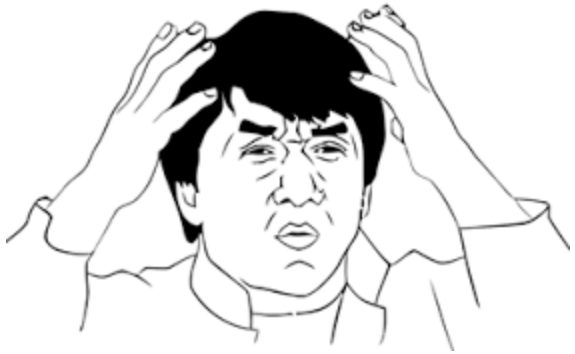

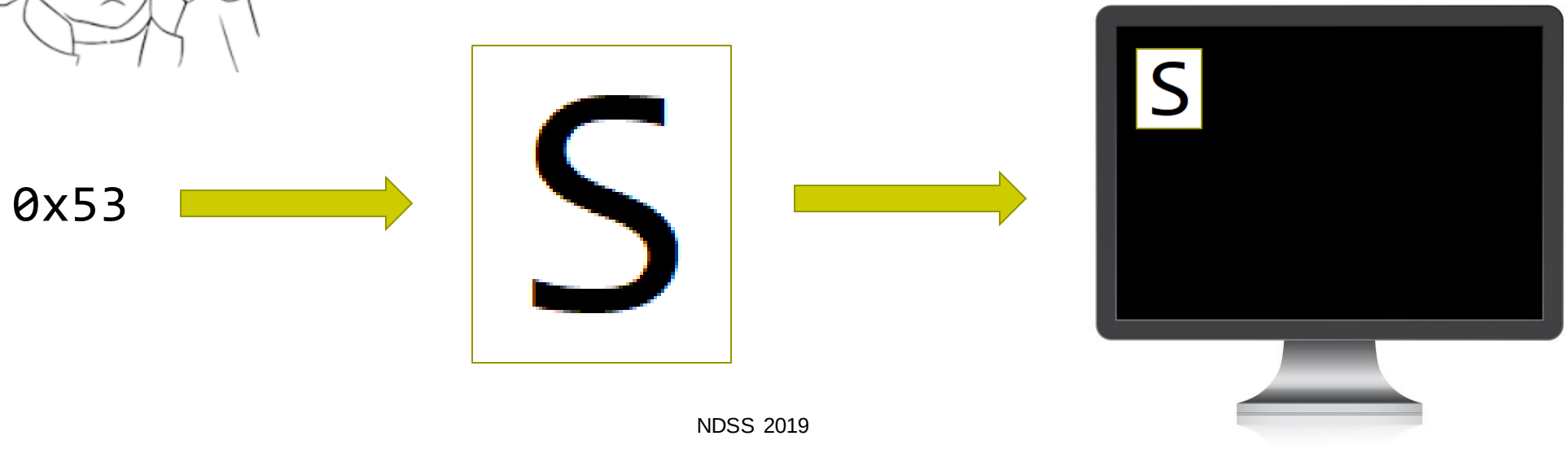

Example

```
static void D32_LCD32_Opaque(...) {
    ...
    do {
        blit_lcd32_opaque_row(dstRow, srcRow, color, width);
        dstRow = (SkPMColor*)((char*)dstRow + dstRB);
        srcRow = (const SkPMColor*)((const char*)srcRow + maskRB);
    } while (--height != 0);
}

static void blit_lcd32_opaque_row(dst, src, color, width) {
    ...
    for (int i = 0; i < width; i++) {
        if (0 == src[i]) {
            continue;
        }
        ...
    }
}
```

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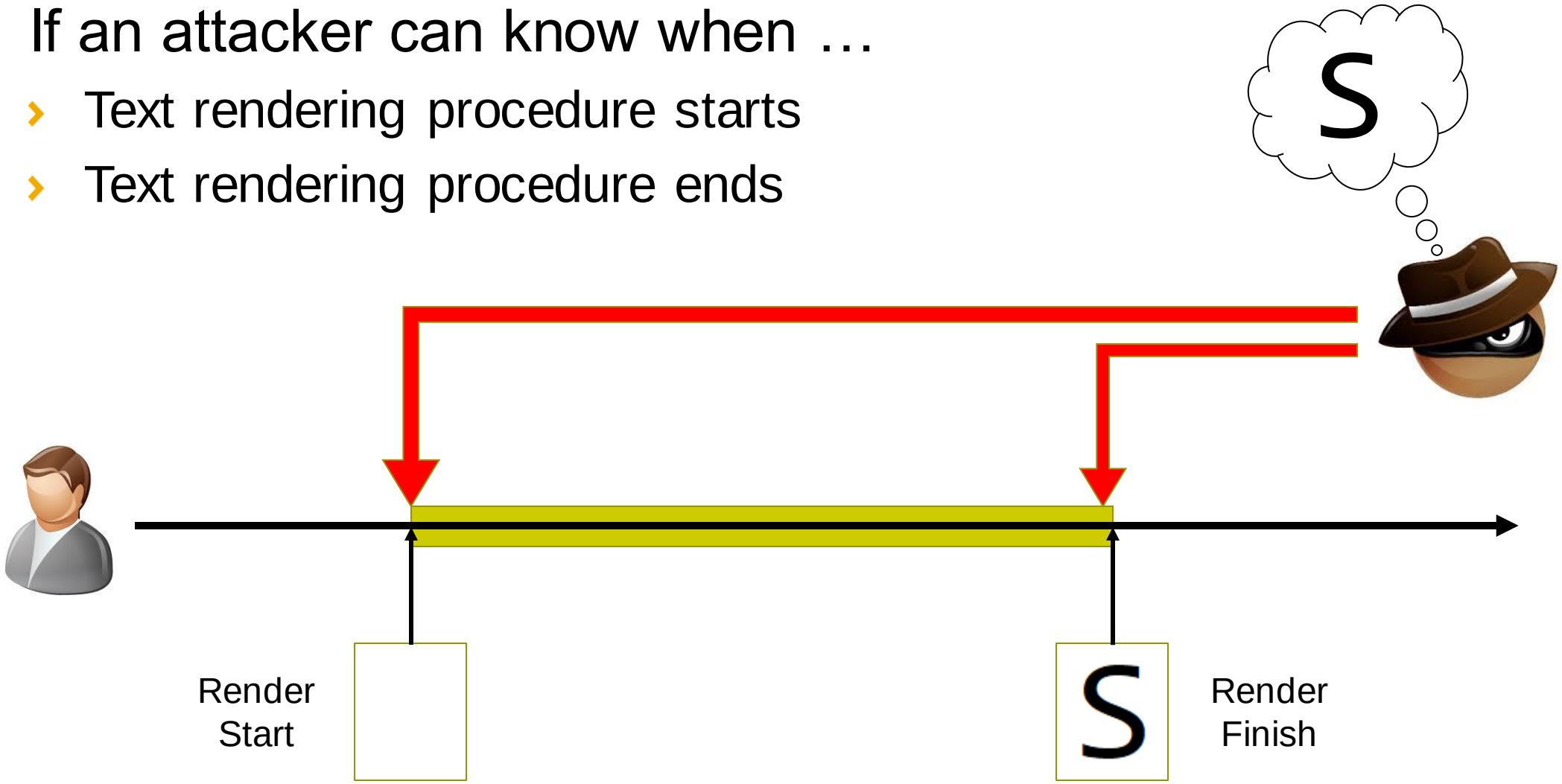
        ...
    }
}
```

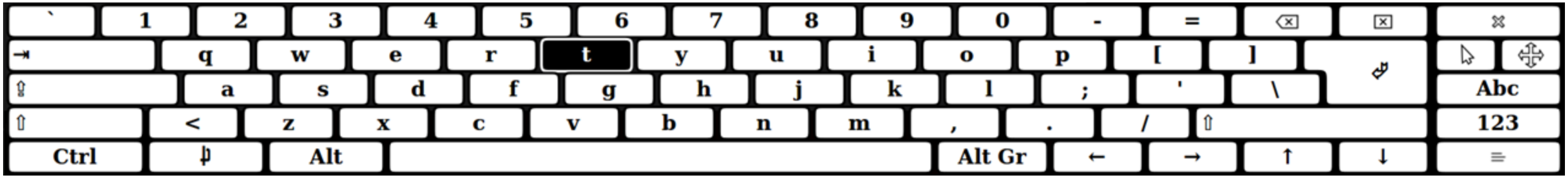
NOT CONSTANT TIME!

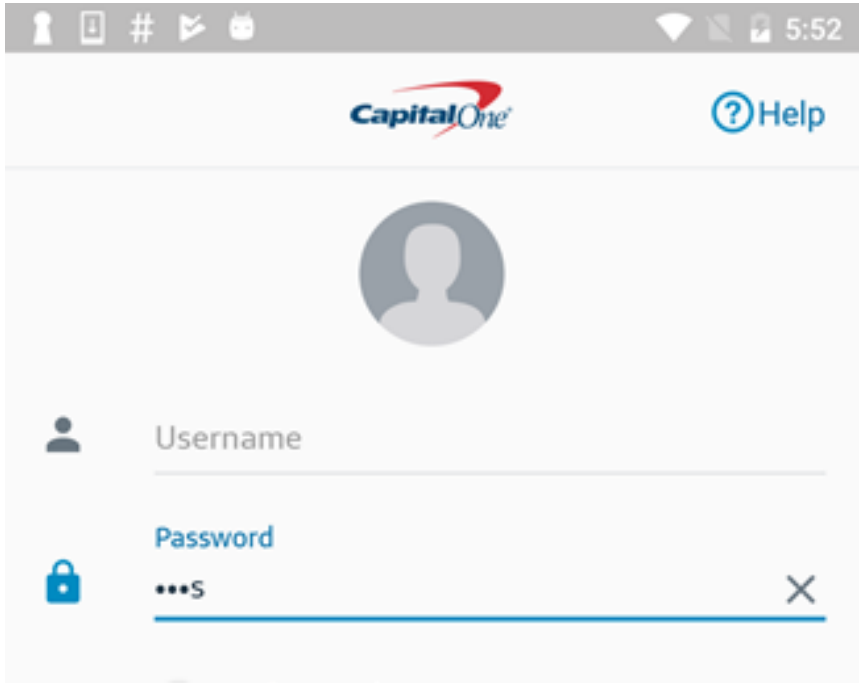
Exploiting the Side-channel

- If an attacker can know when …
  - Text rendering procedure starts
  - Text rendering procedure ends



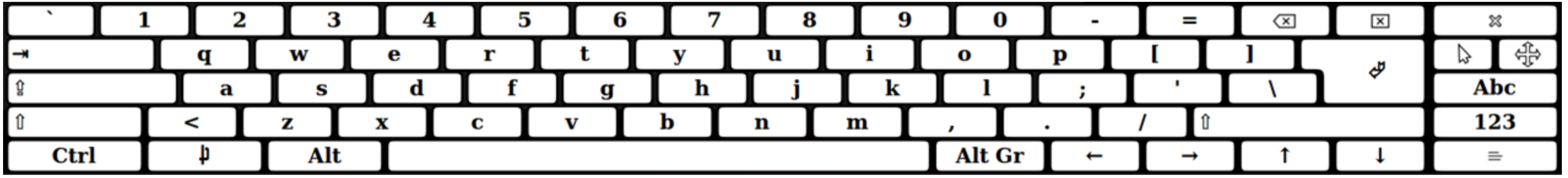
Potentially Vulnerable Apps





Example: Onboard

- Onscreen keyboard
  - Ubuntu 16.04



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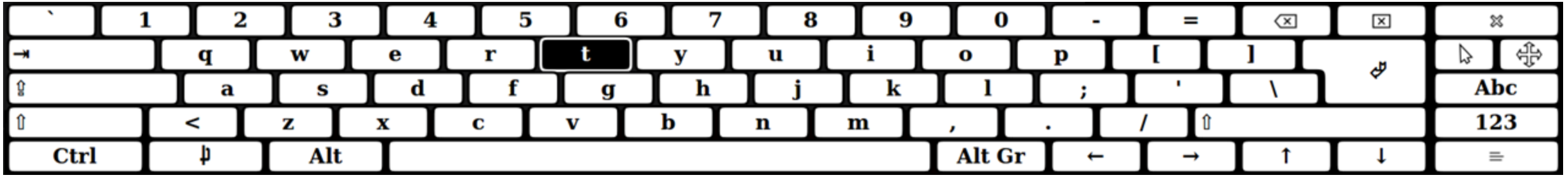
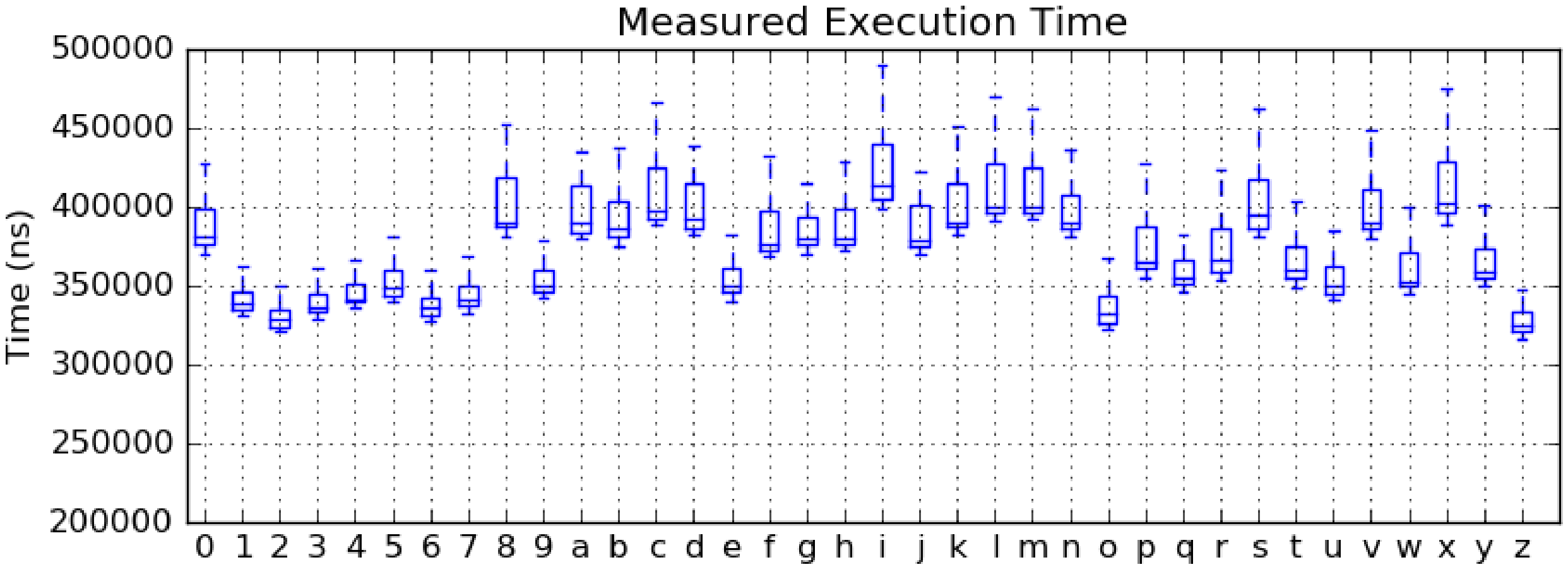


Attack: Onboard



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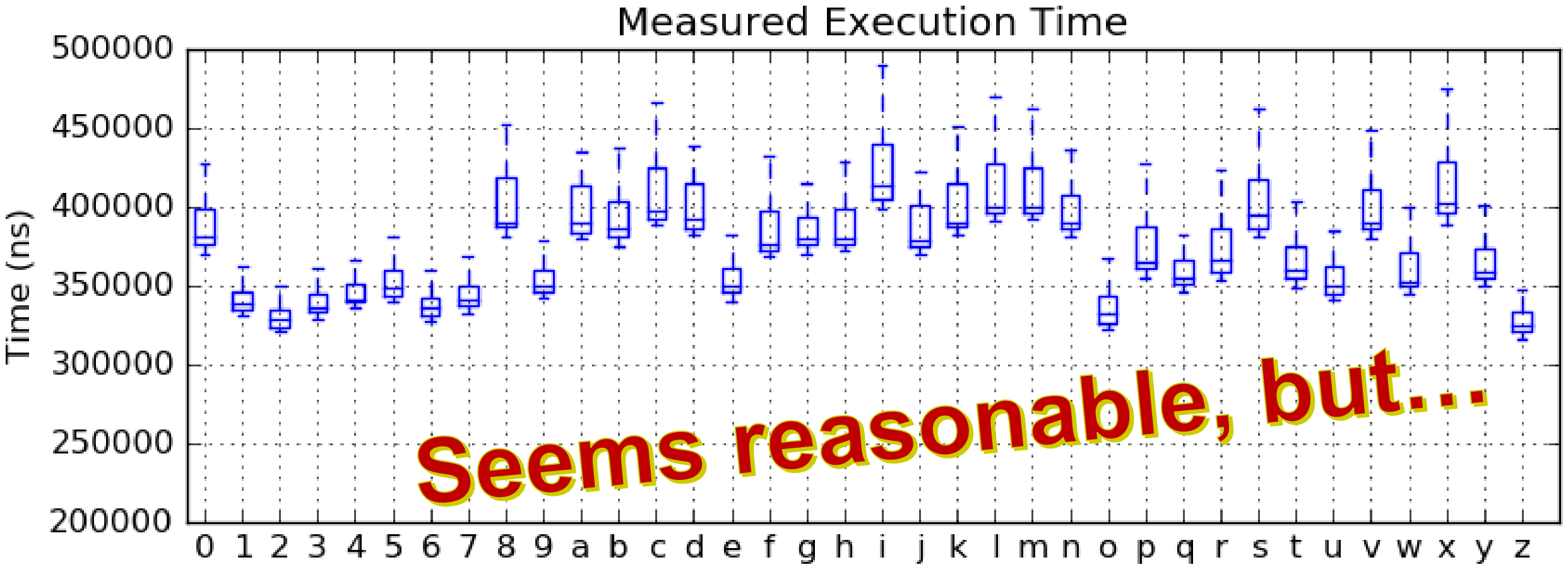
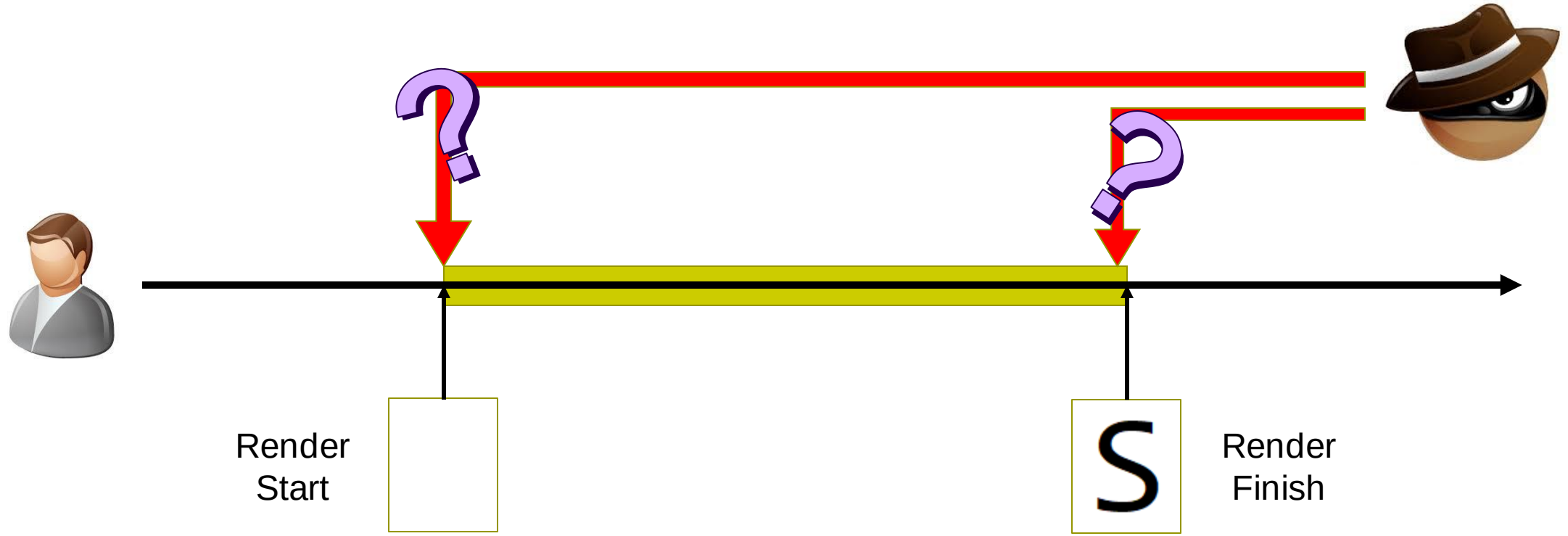


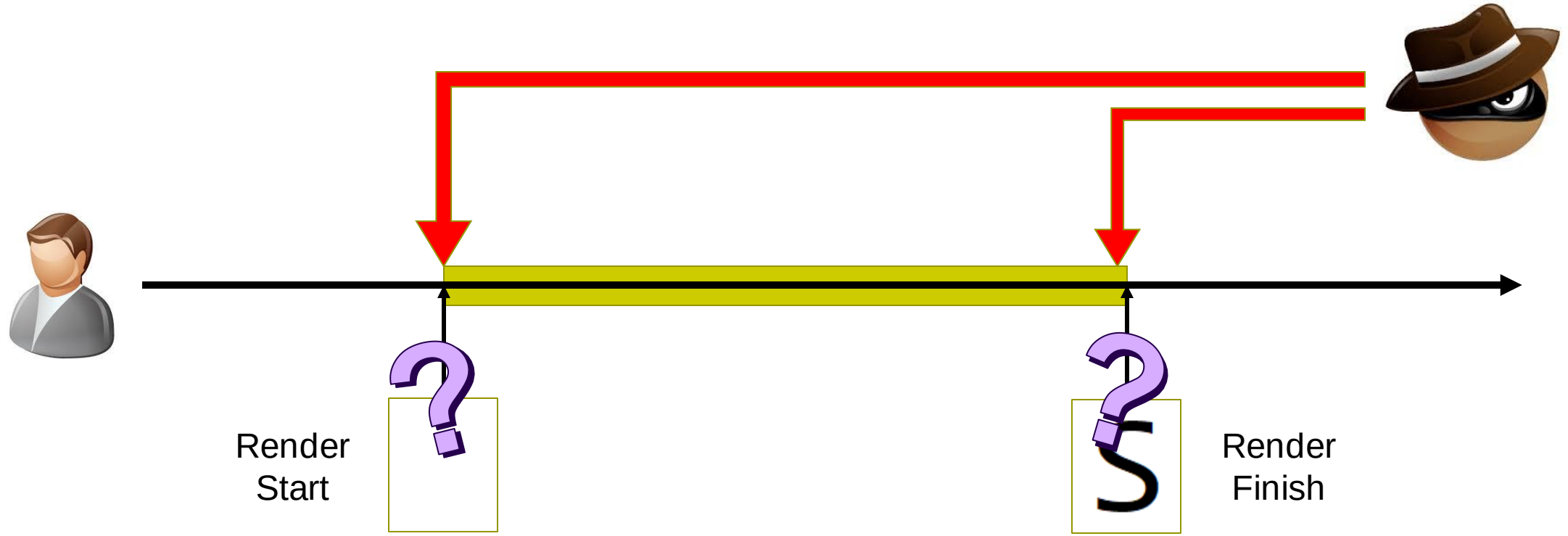
Challenges

- How to perform measurement?
  - Unprivileged attacker



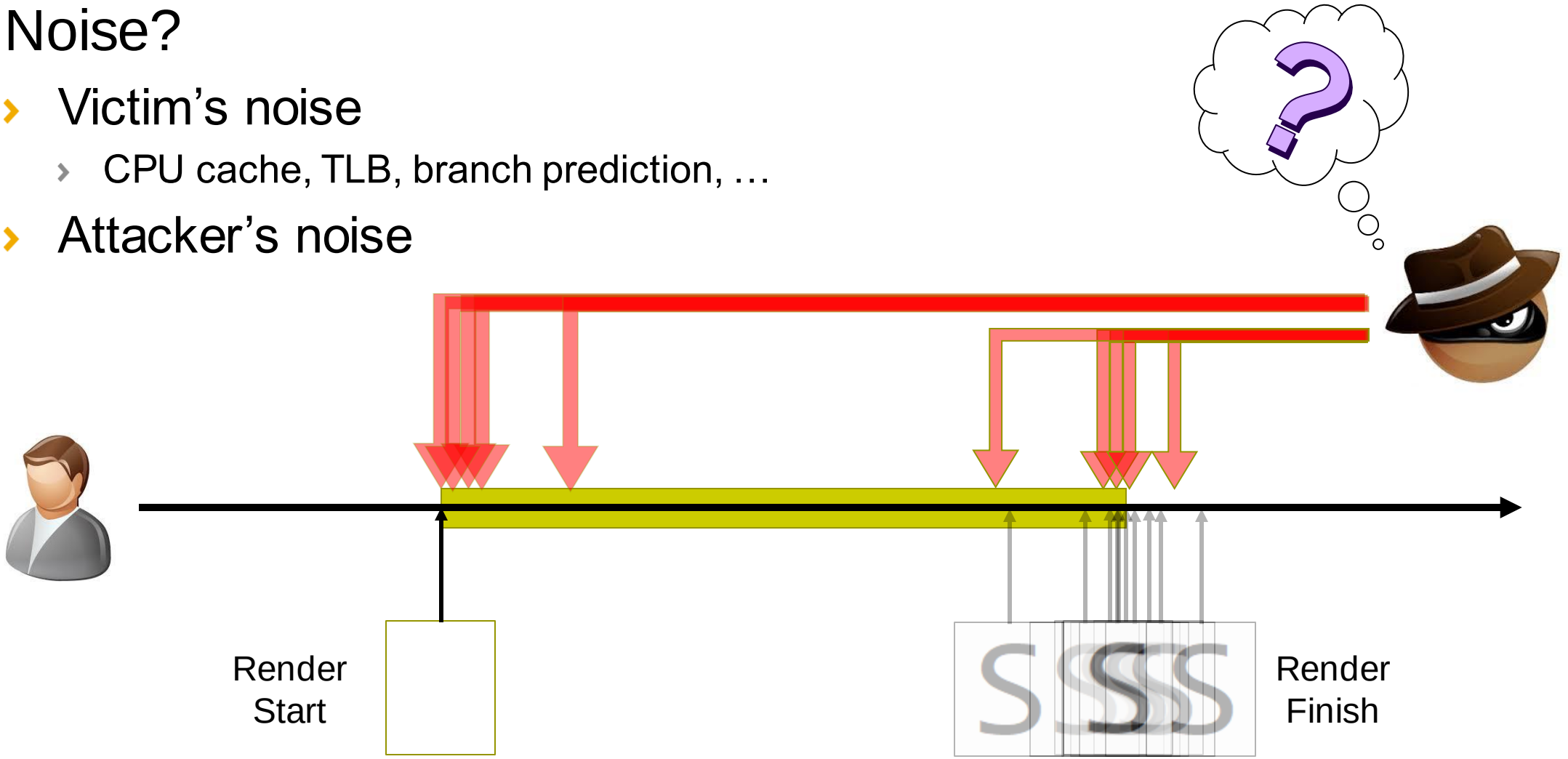
Challenges

- How to find start/end of rendering?
  - Millions of code. Multiple libraries.
  - Varies from application to application.



Challenges

- Noise?
  - Victim's noise
    - CPU cache, TLB, branch prediction, …
  - Attacker's noise



Challenges

- Perform measurement without privilege
- Discover side-channel in graphic libraries
- Noise-resistant key prediction

Threat Model

- Attacker's goal
  - Eavesdrop sensitive text input that will be rendered on screen
    - PIN, passwd, etc

- Attacker's capabilities
  - Access to same model/version of victim's hardware and graphic libraries
    - Offline profiling
  - Launch unprivileged process alongside victim process
    - Online attack

Performing Measurement

…

libA.so

renderStart()

renderEnd()

…

…

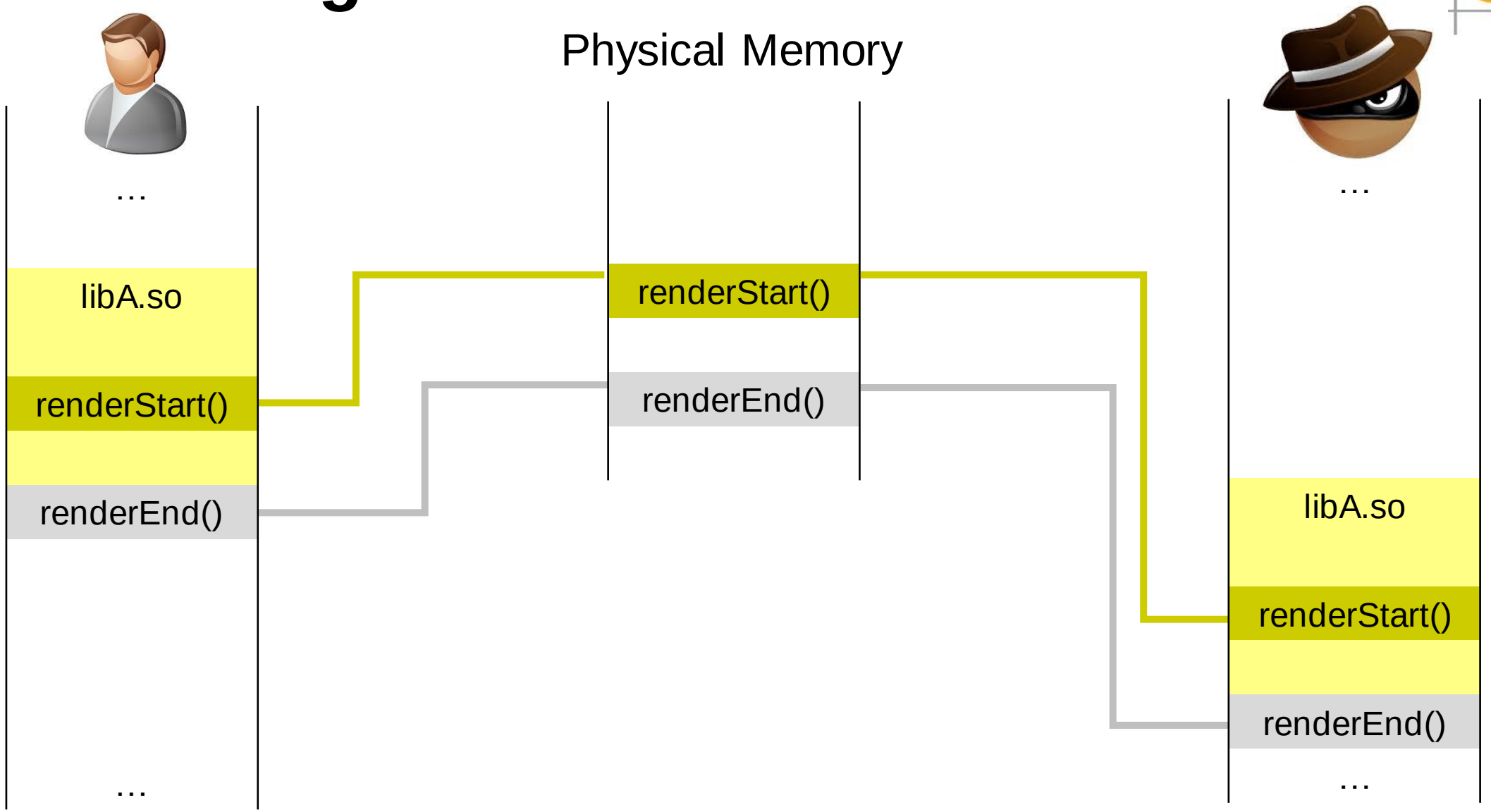
libA.so

renderStart()

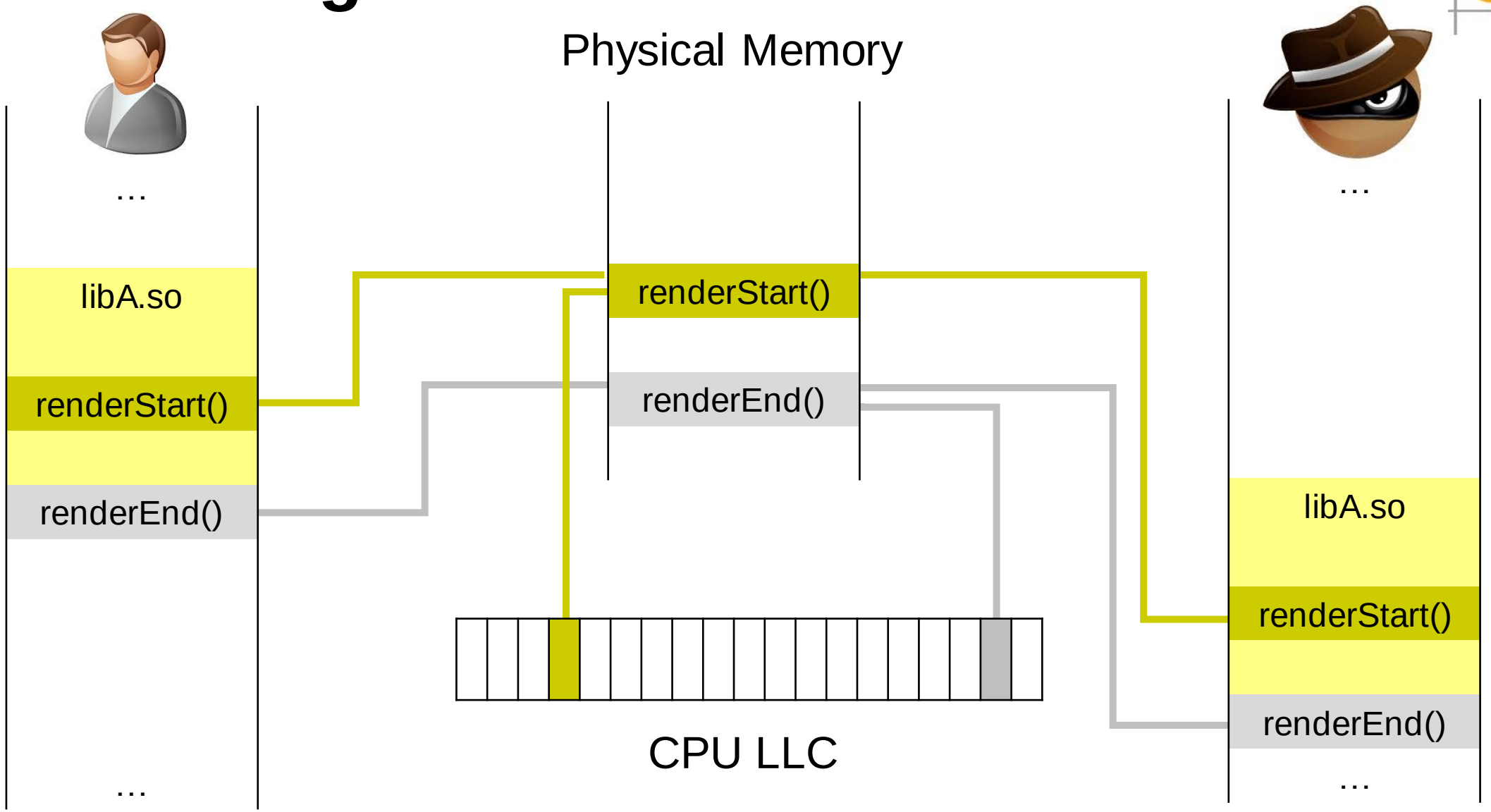
renderEnd()

…

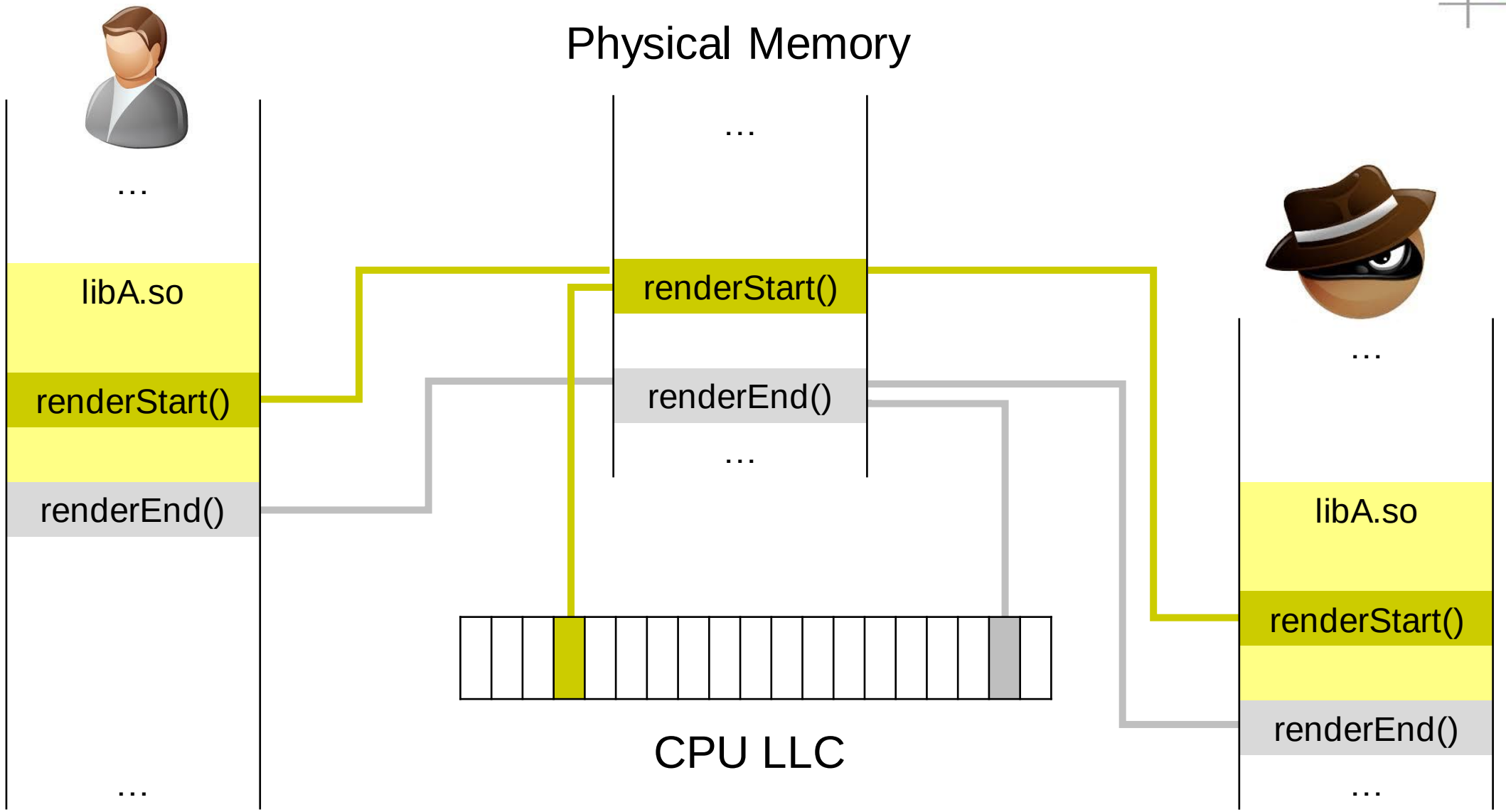
Performing Measurement



Performing Measurement



Flush+Reload



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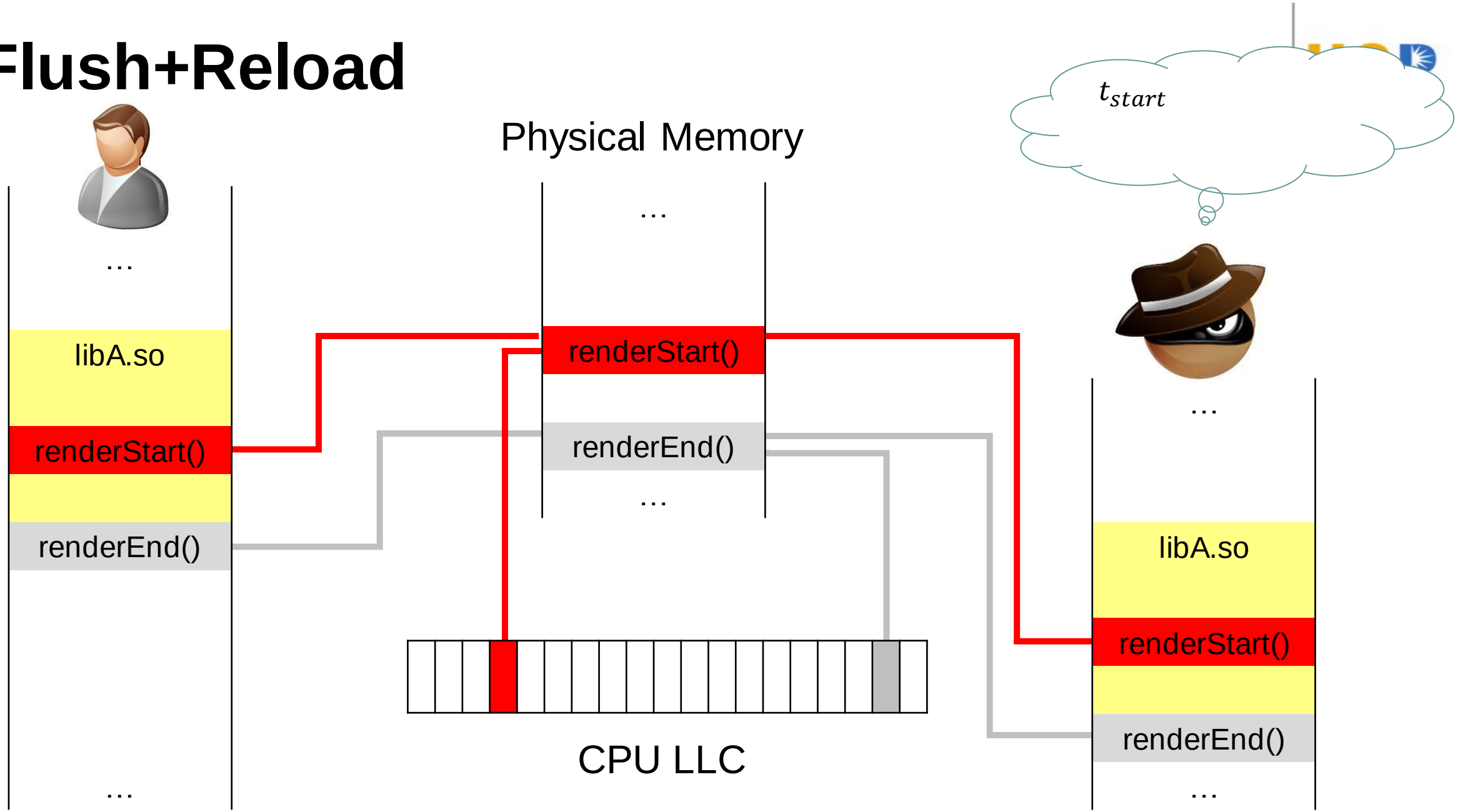

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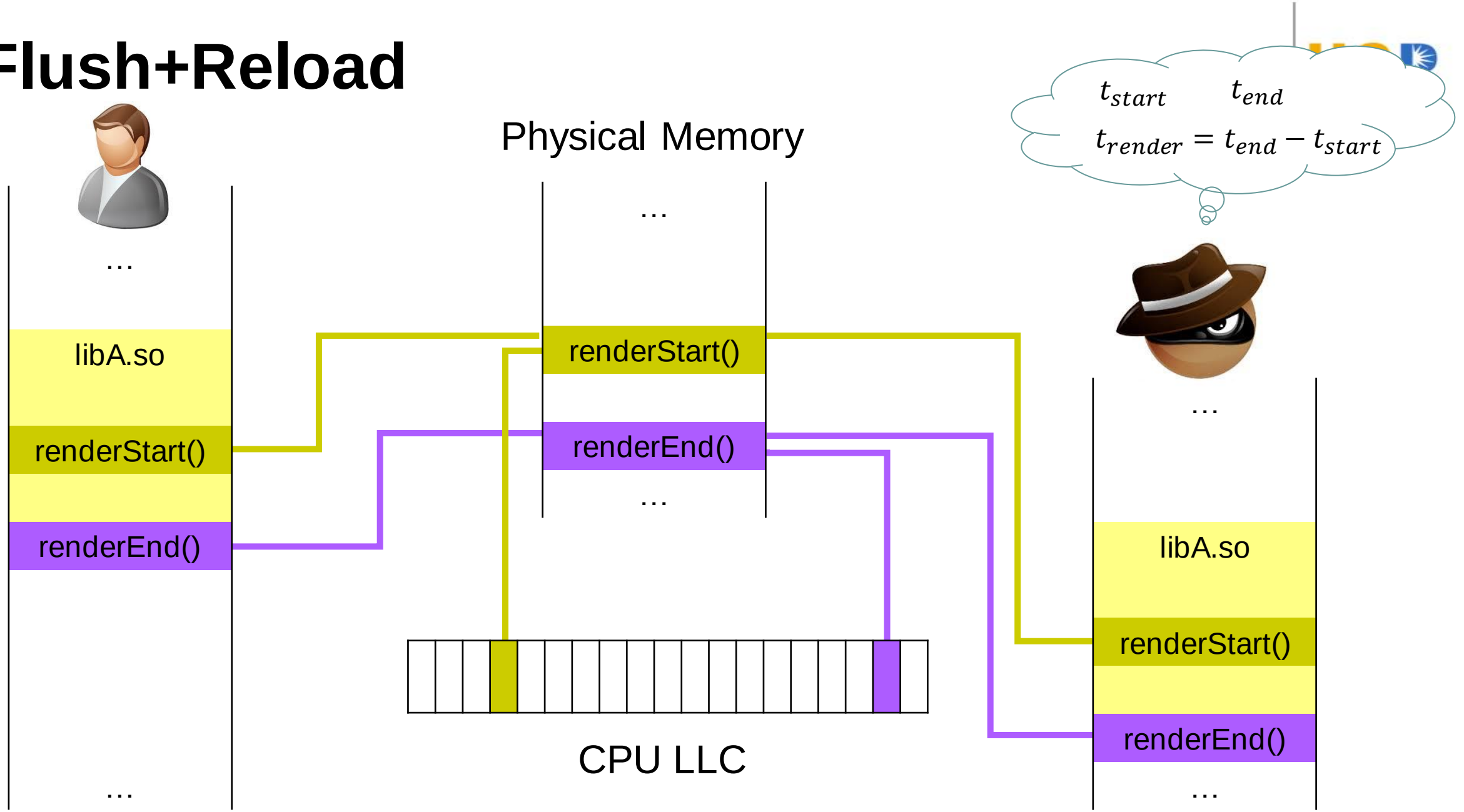
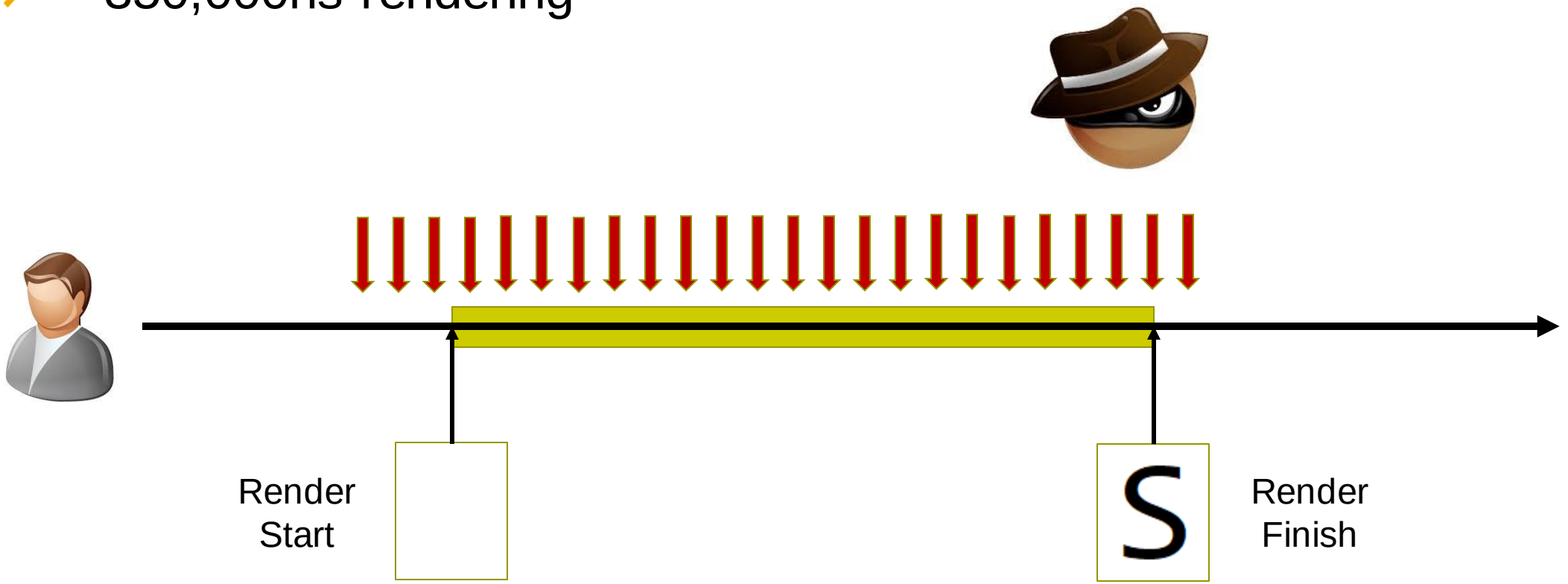


Measurement Resolution

- Onboard
  - ~ 600ns per round
  - ~ 350,000ns rendering



Side-channel Discovery

- Instrument graphic libraries & collect victim trace

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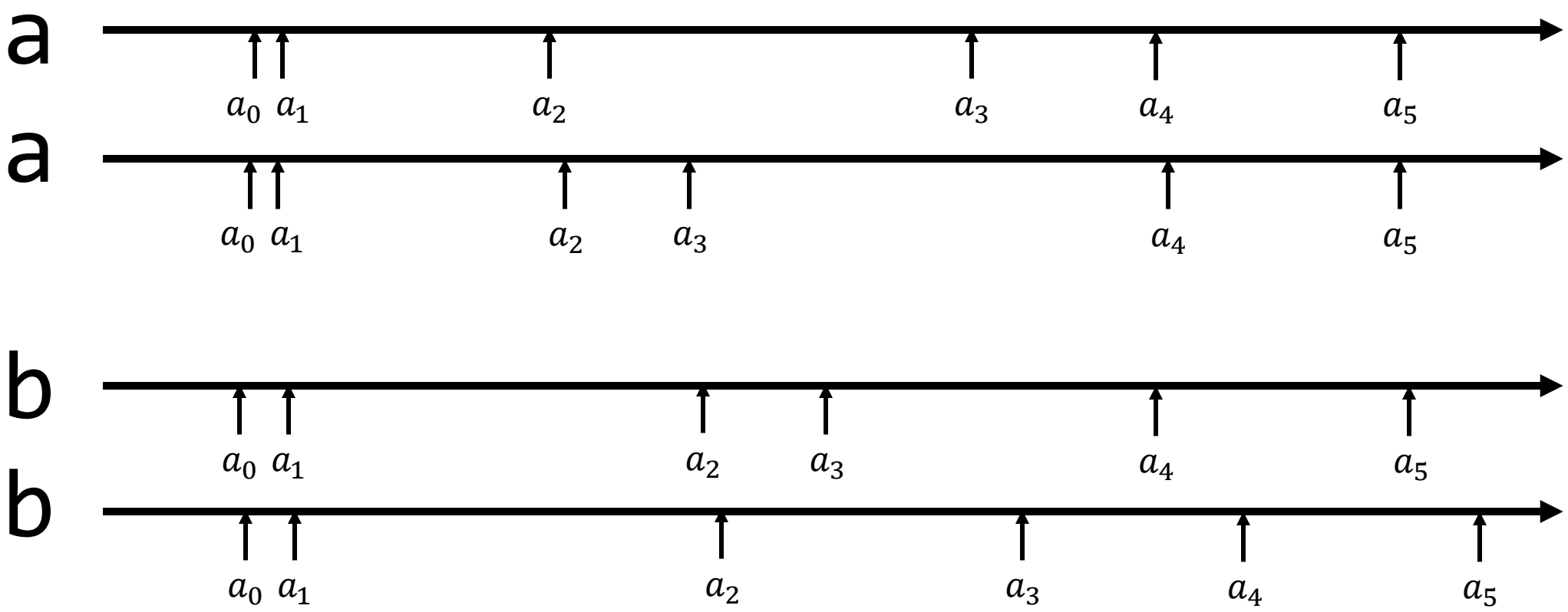

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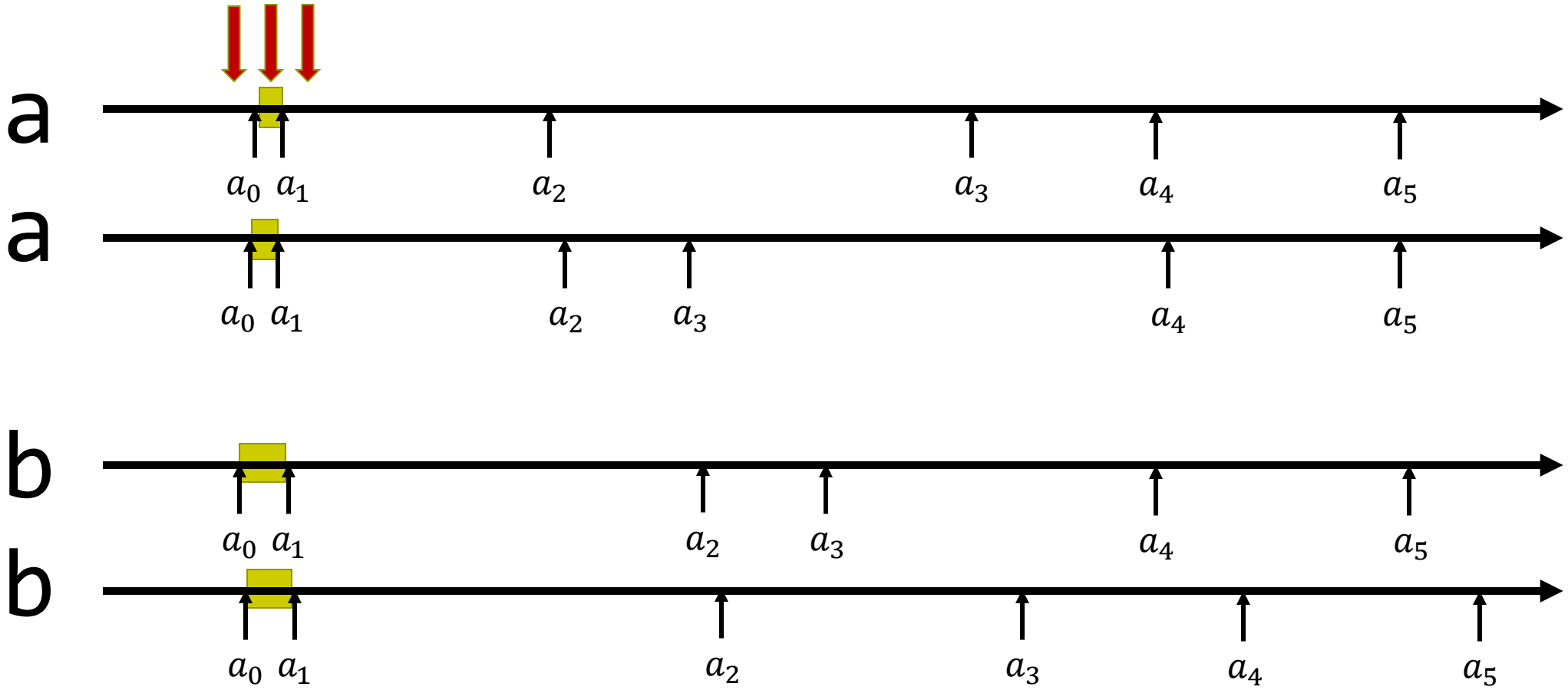

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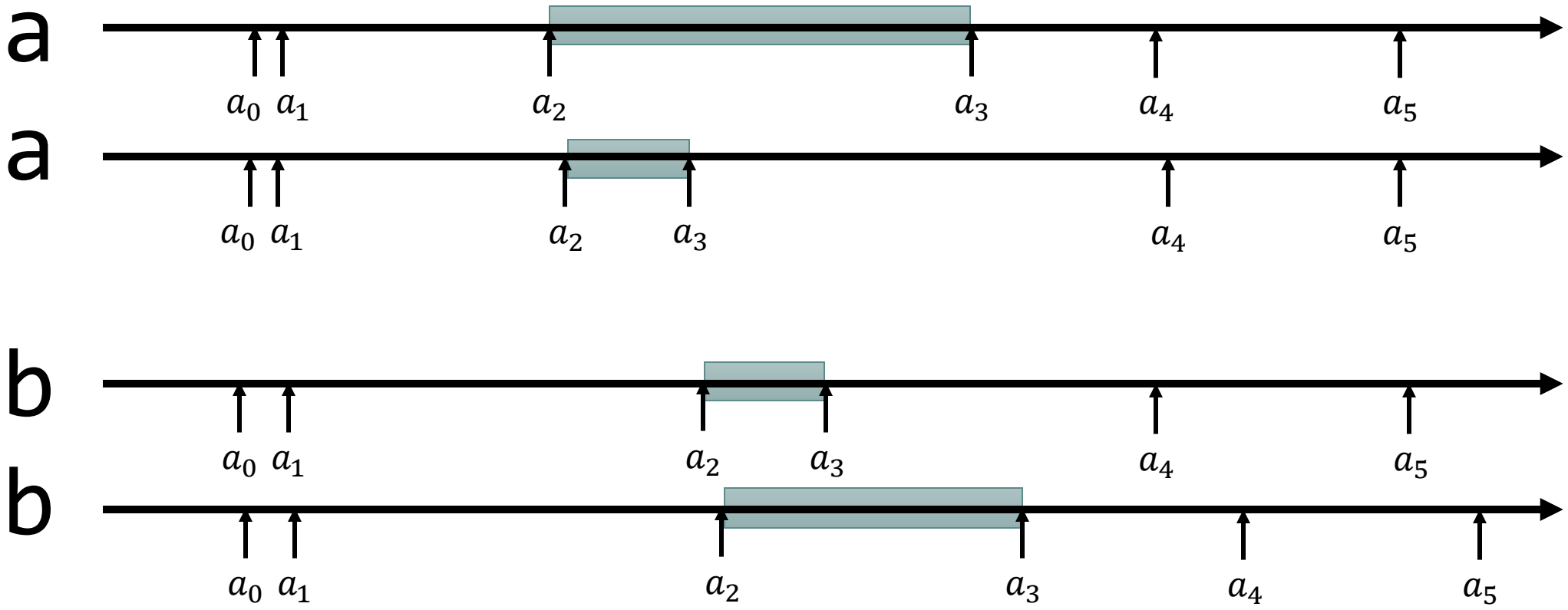

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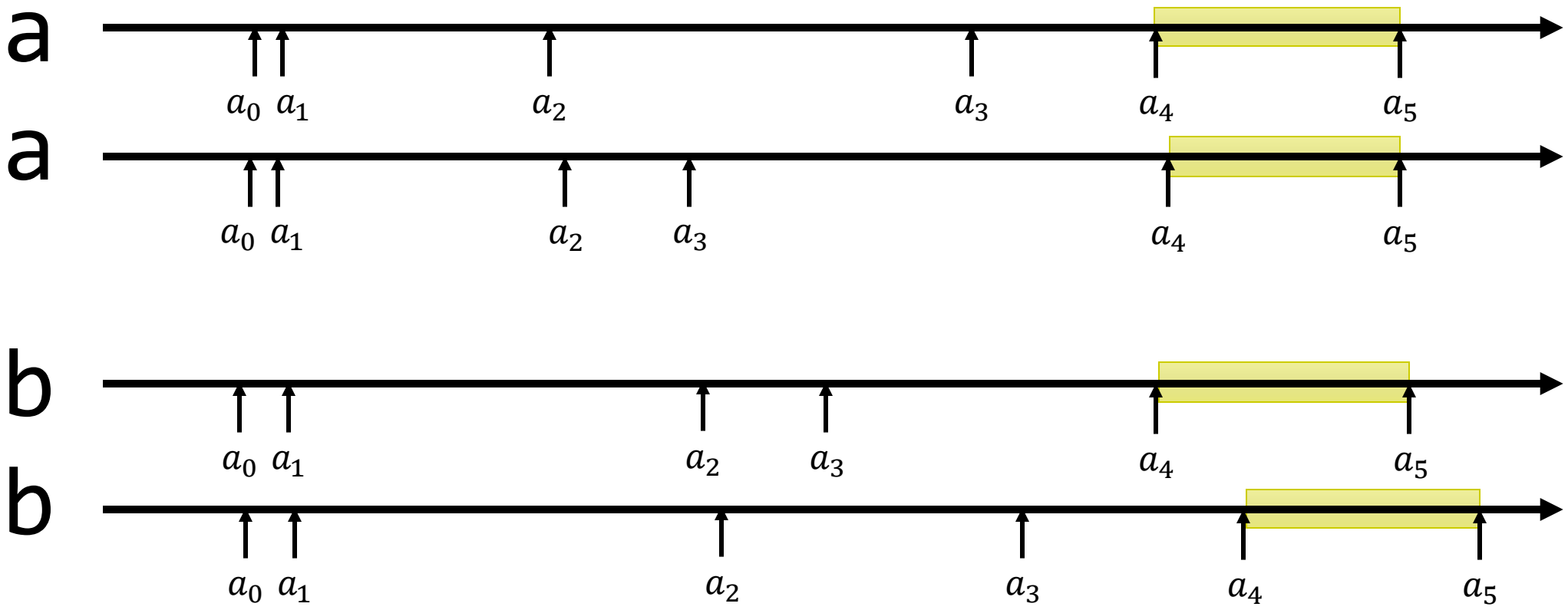

Side-channel Discovery

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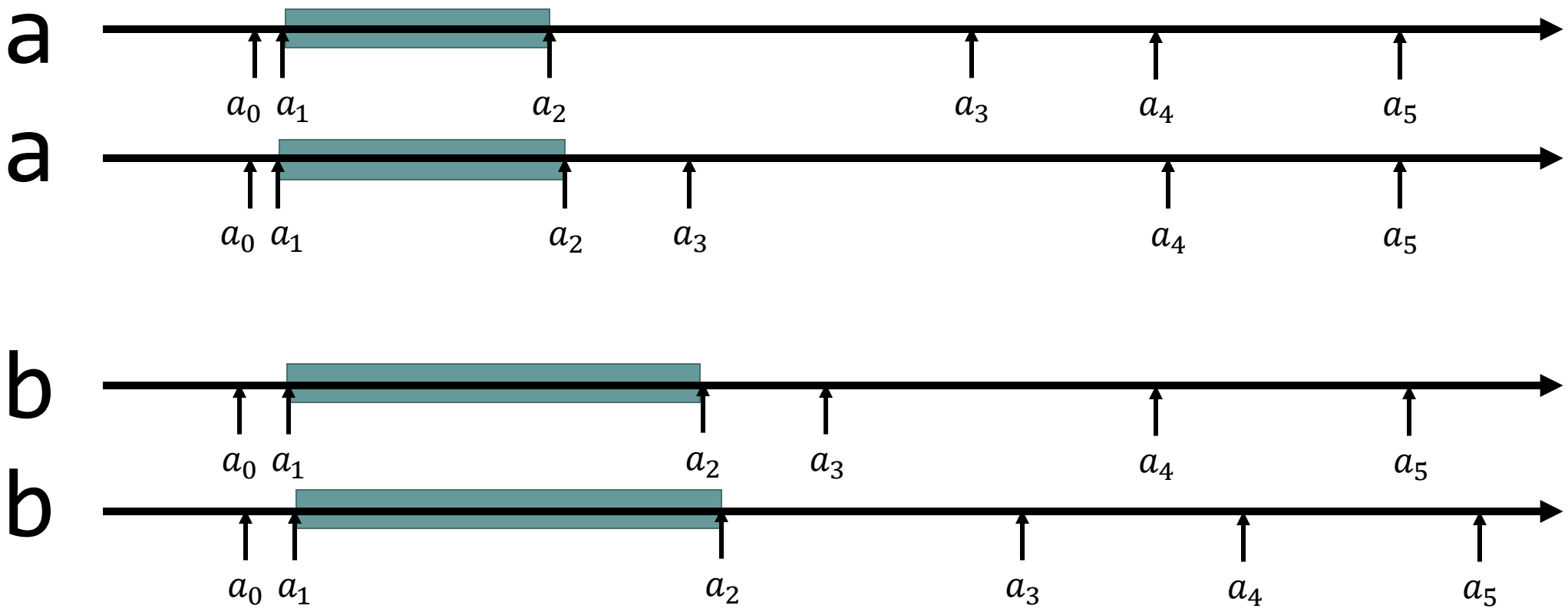
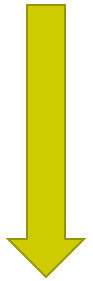


Side-channel Discovery

- Select pairs of addresses (a_x, a_y)
  - $dist(a_x, a_y)$ is long enough for flush+reload to measure
  - $dist(a_x, a_y)$ is stable across the same input
  - $dist(a_x, a_y)$ has high information gain
  - a_x, a_y not affected by cache architecture

> 6 million pairs



~1000 pairs

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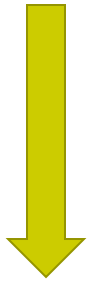
  - $dist(a_x, a_y)$ is stable across the same input
  - $dist(a_x, a_y)$ has high information gain
  - a_x, a_y not affected by cache architecture
- Sanity Check: Run attack offline
  - Filter out addressed affected system noise
  - Filter out addressed affected by instrumentation

> 6 million pairs



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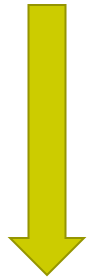
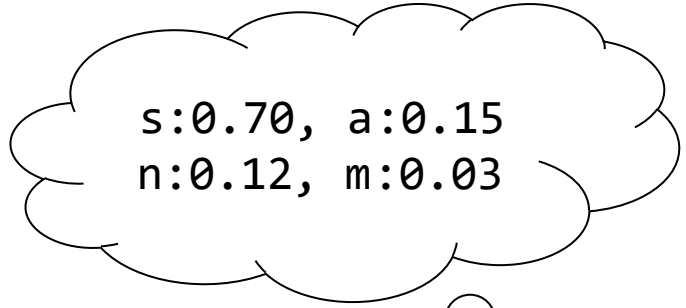


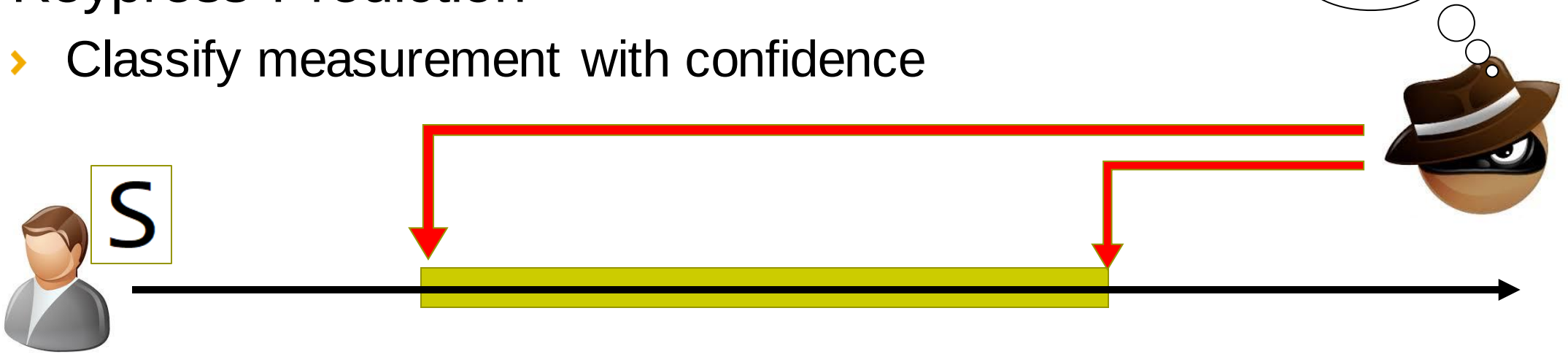
<100 pairs

Keypress Prediction

- Machine Learning Model Construction
  - Collect measurements for all different user inputs
  - Random Forest with 100 estimators



- Keypress Prediction
  - Classify measurement with confidence



Challenges

- ✓ Perform measurement without privilege
- ✓ Discover side-channel in graphic libraries
- ✓ Noise-resistant key prediction

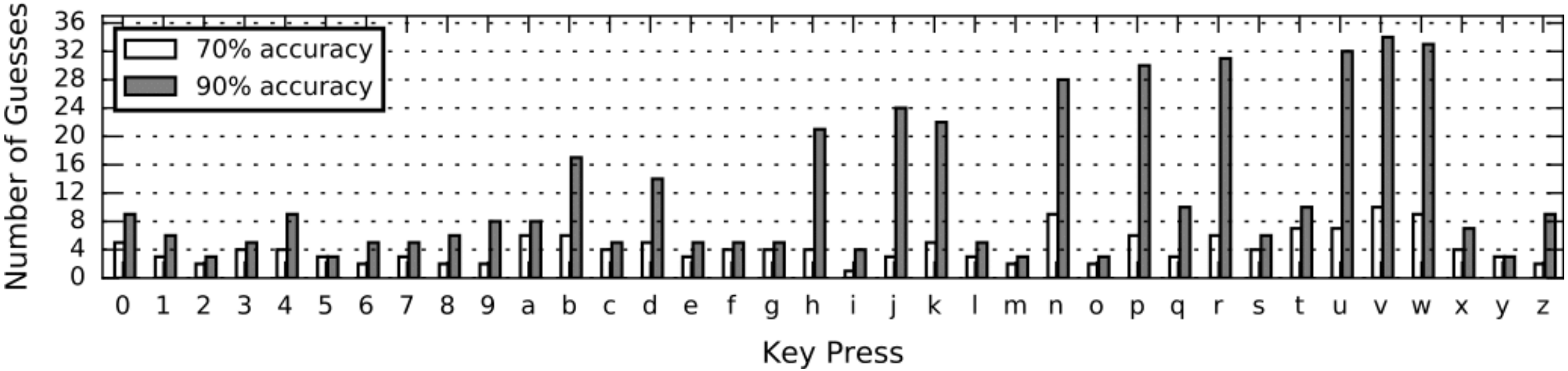
Attack 1: Onboard

- Ubuntu 16.04, Intel Core i7-4770

#	Address	Library	Function
1	0x75a40	libcairo.so	_cairo_surface_create_scratch
	0x69e40	libcairo.so	_cairo_scaled_font_map_lock
2	0x69e40	libcairo.so	_cairo_scaled_font_map_lock
	0x41f40	libcairo.so	_cairo_intern_string
3	0x24440	libcairo.so	_cairo_clip_copy_with_translation
	0xbe000	libcairo.so	_cairo_ft_unscaled_font_lock_face
4	0x6b900	libcairo.so	_cairo_path_fixed_approximate_stroke_extents
	0x41700	libcairo.so	_intern_string_pluc
5	0x6a5c0	libcairo.so	_cairo_scaled_font_thaw_cache
	0x41700	libcairo.so	_intern_string_pluc

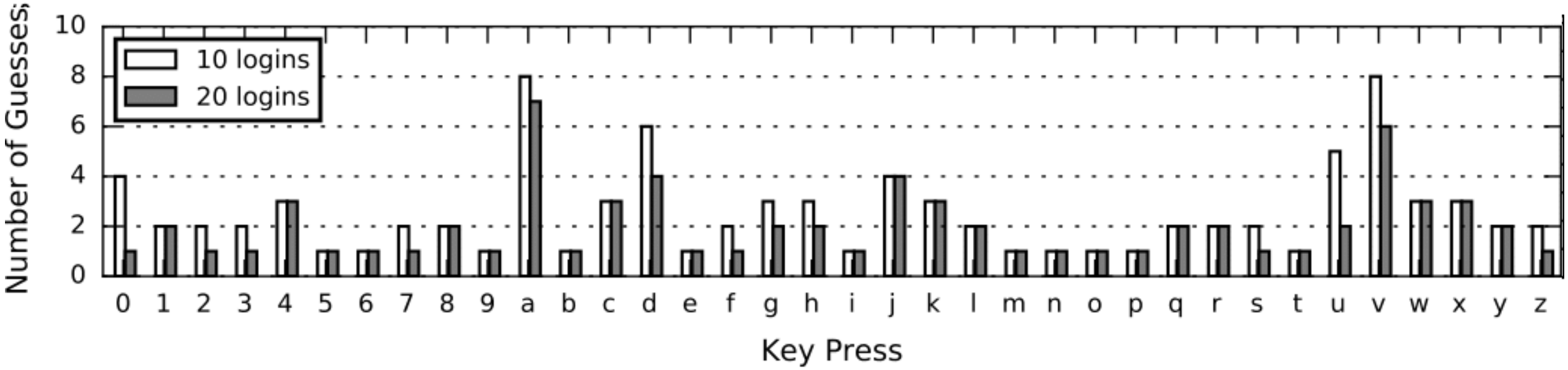
Attack 1: Onboard

- Single keypress prediction



Attack 1: Onboard

- Single keypress prediction
- Augment 1: Multiple logins



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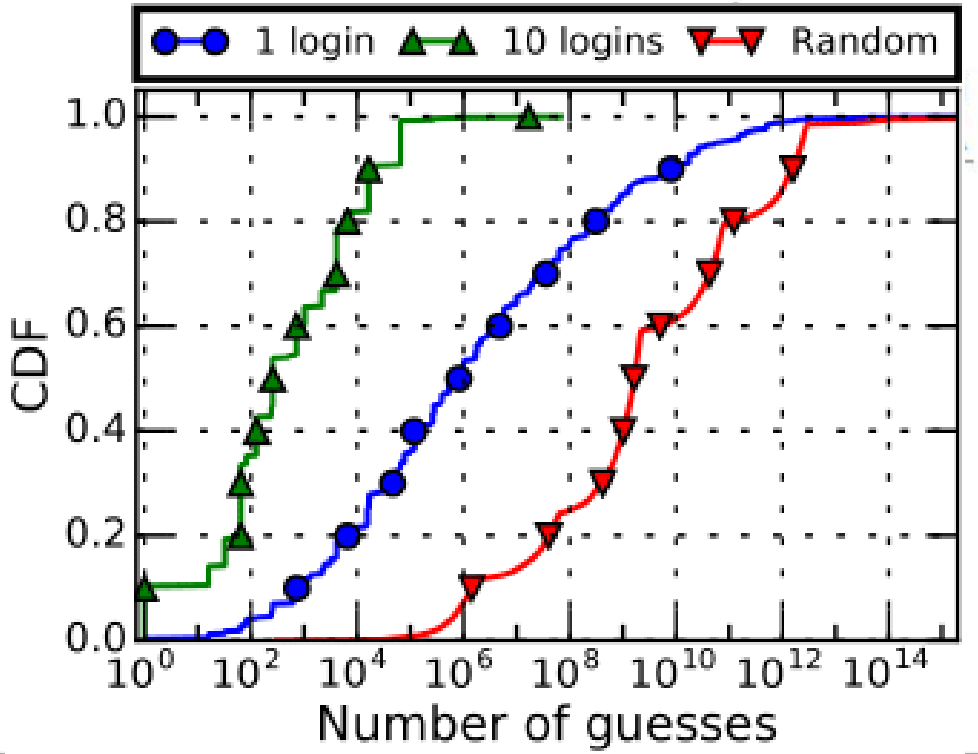
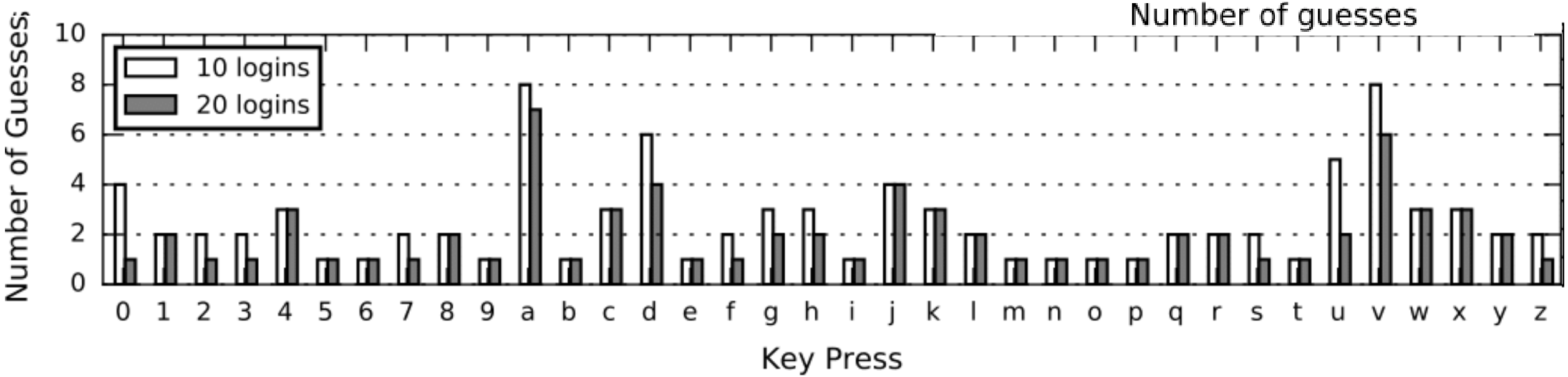
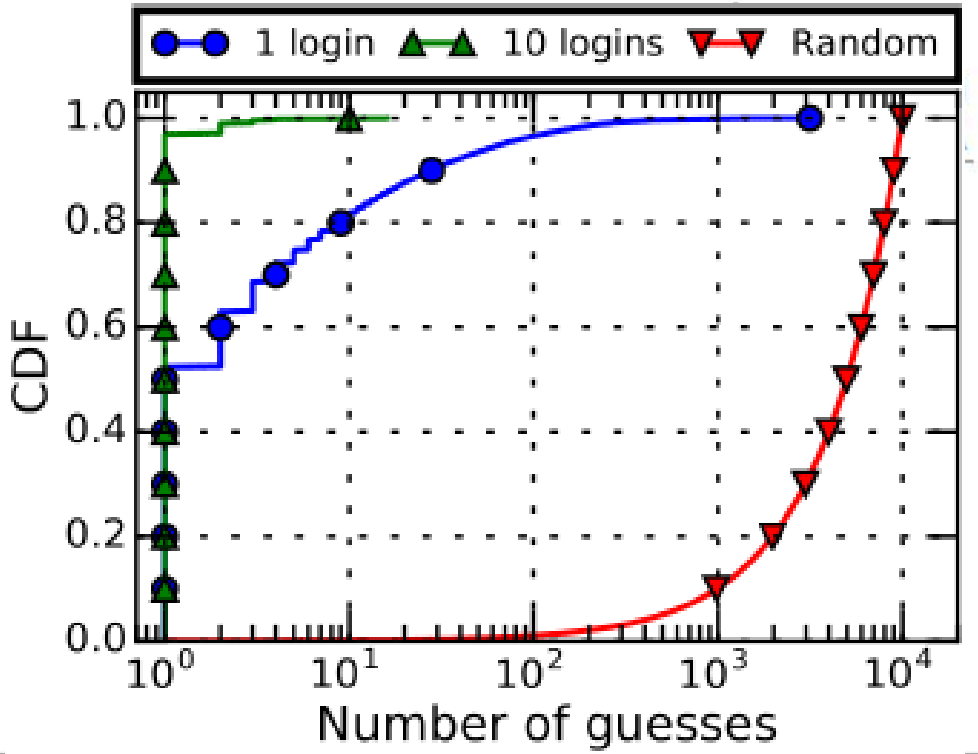
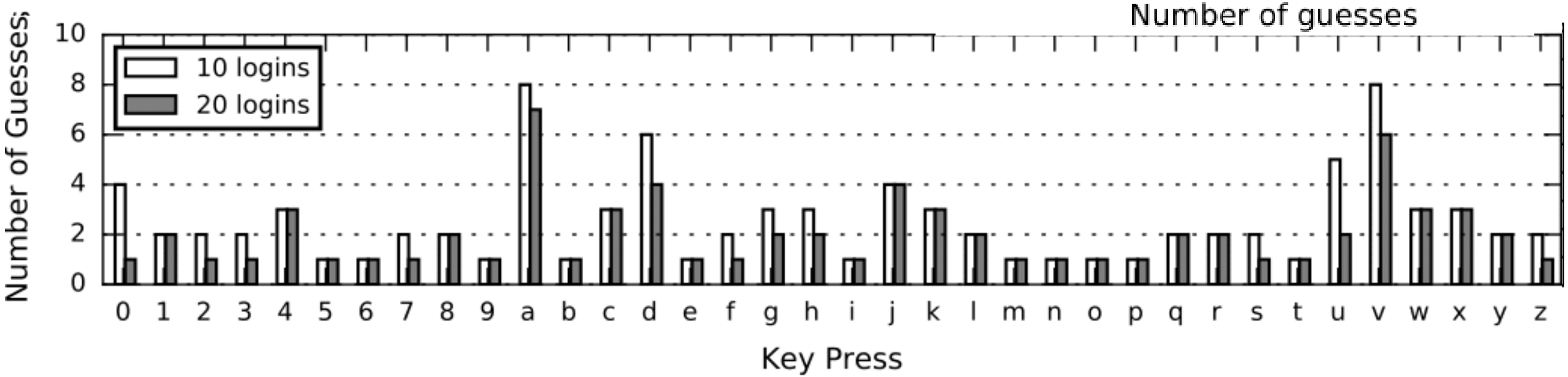




Attack 1: Onboard

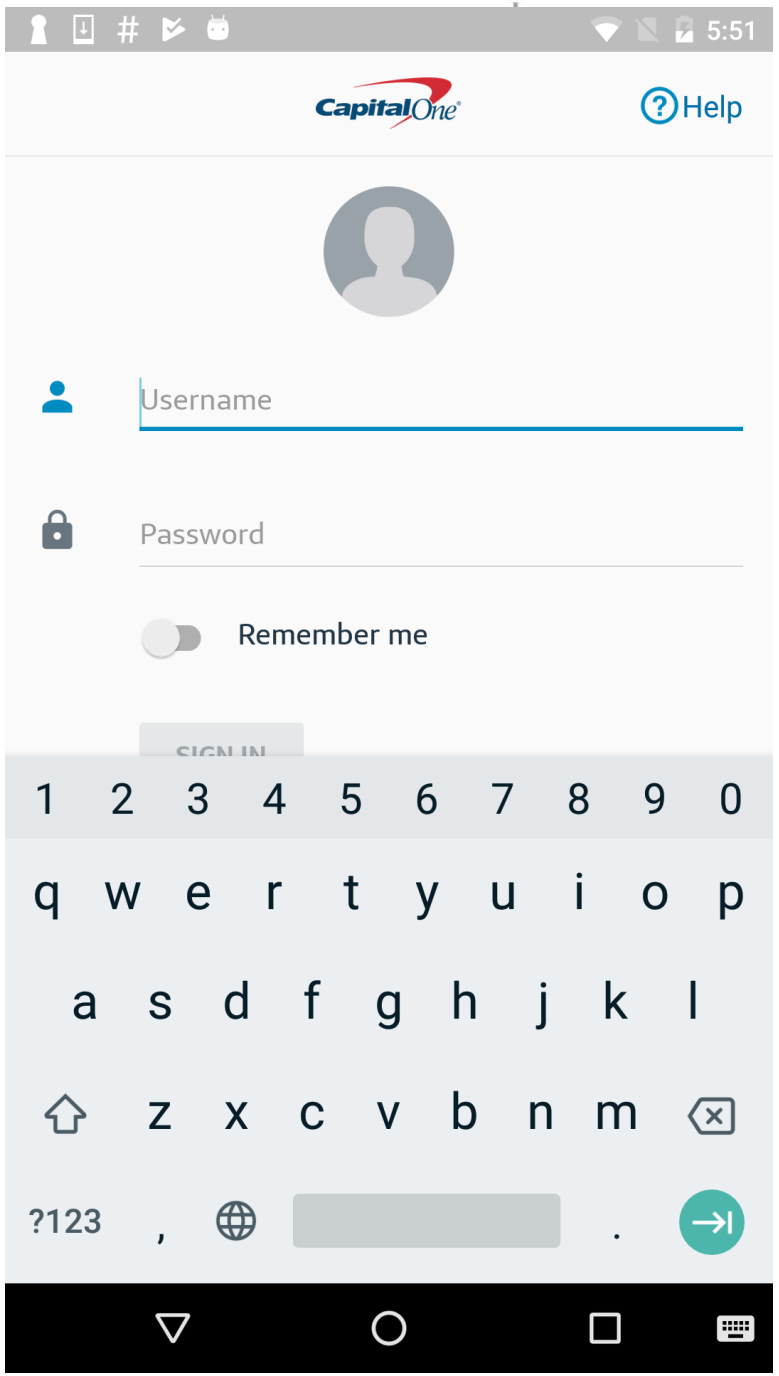
- Single keypress prediction
- Augment 1: Multiple logins
- Augment 2: Dictionary





Attack 2: Capital One

- Huawei Nexus 6P. Android 8.0
- Flush+reload => Evict+reload
  - Resolution 20x lower than Intel



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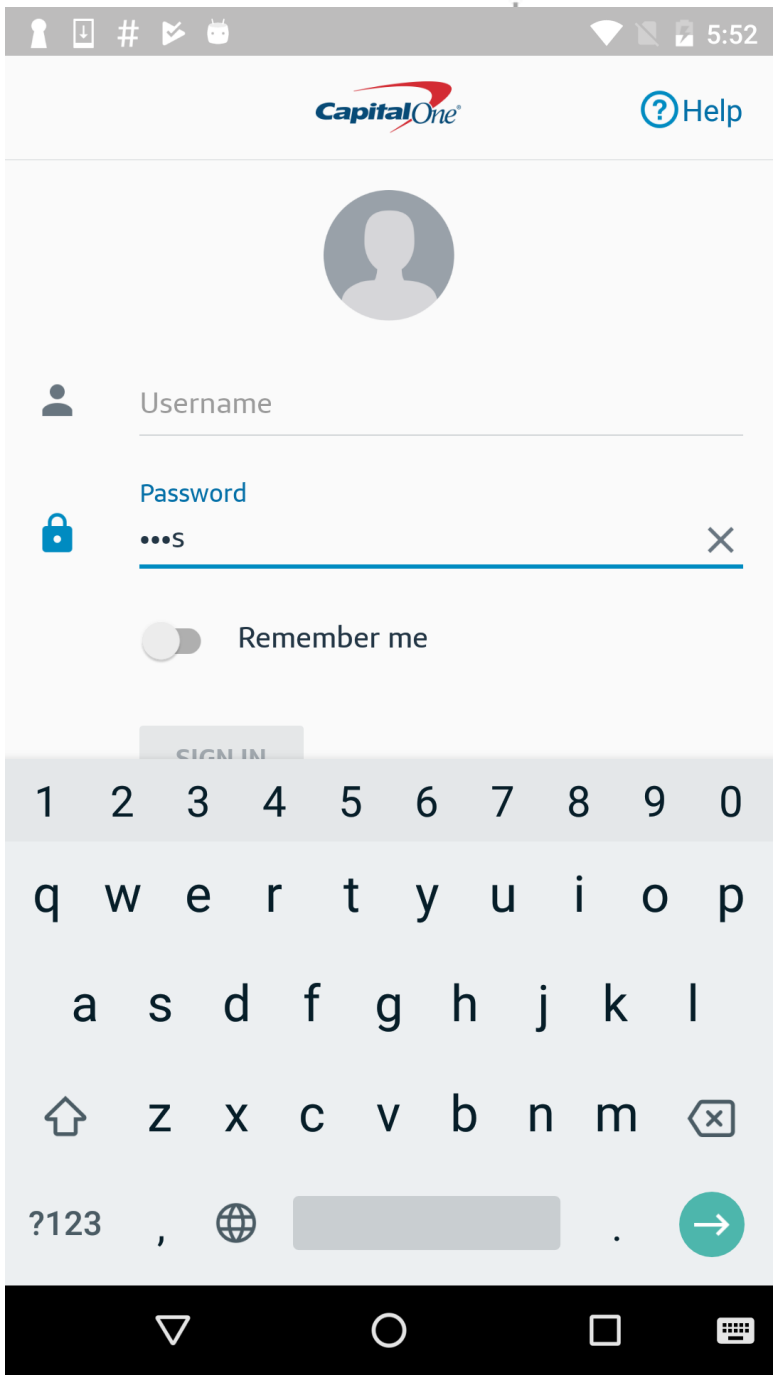

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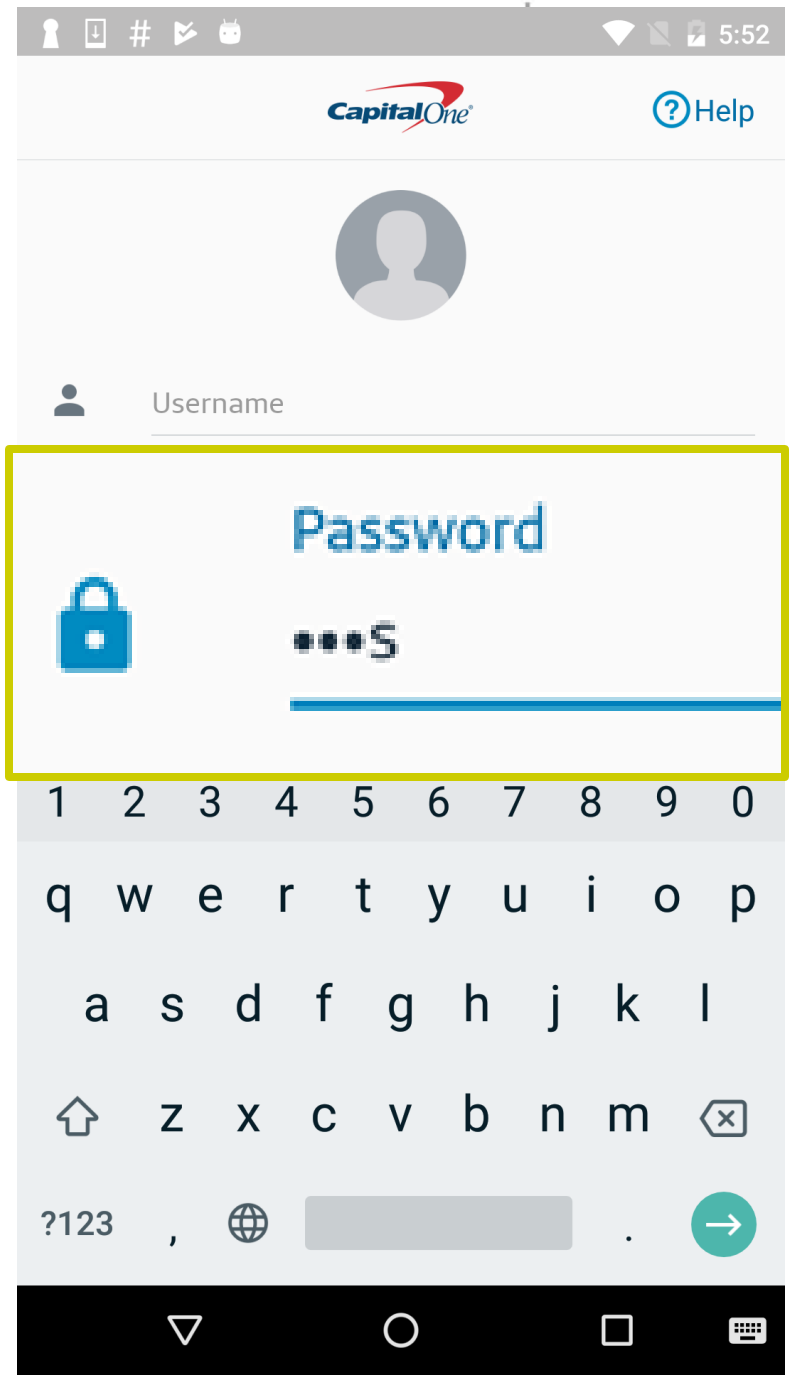
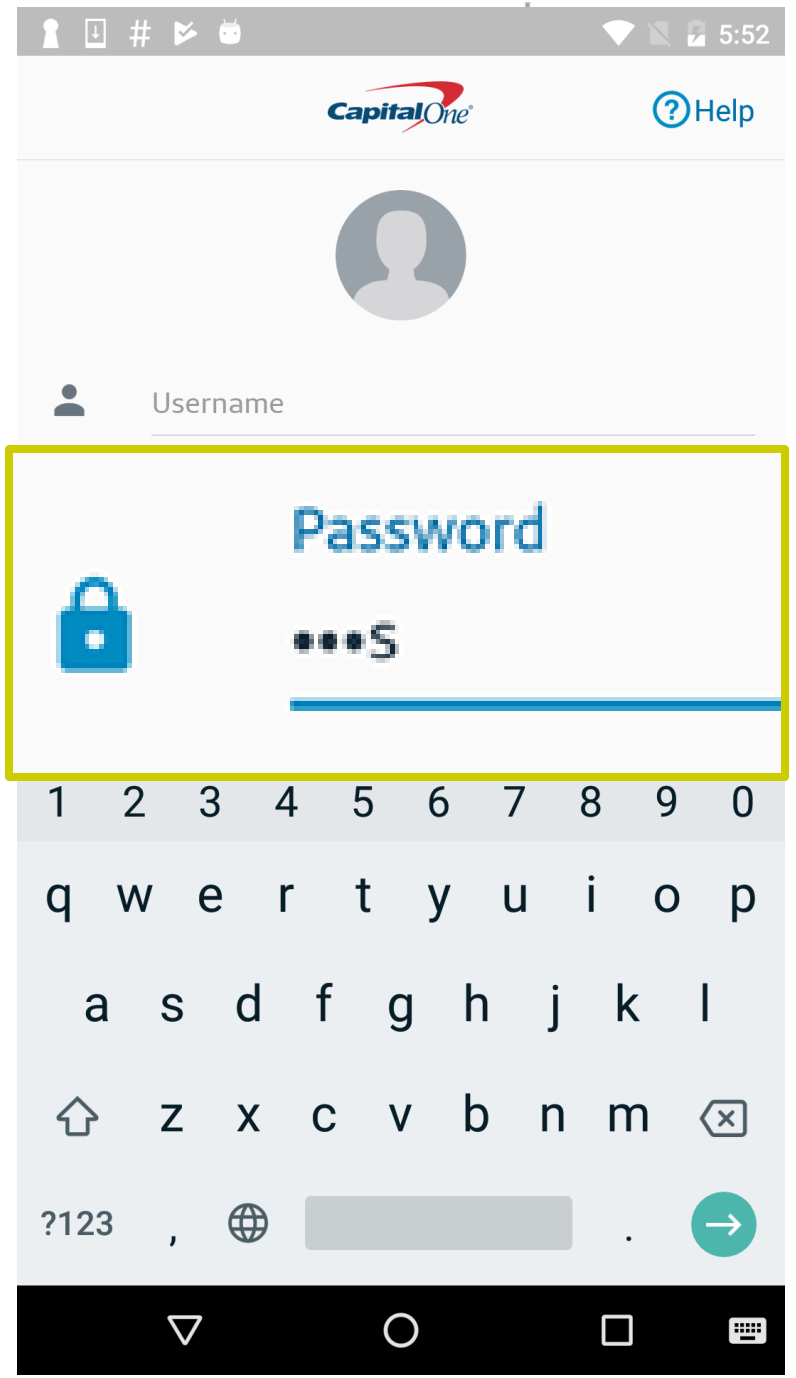


Attack 2: Capital One

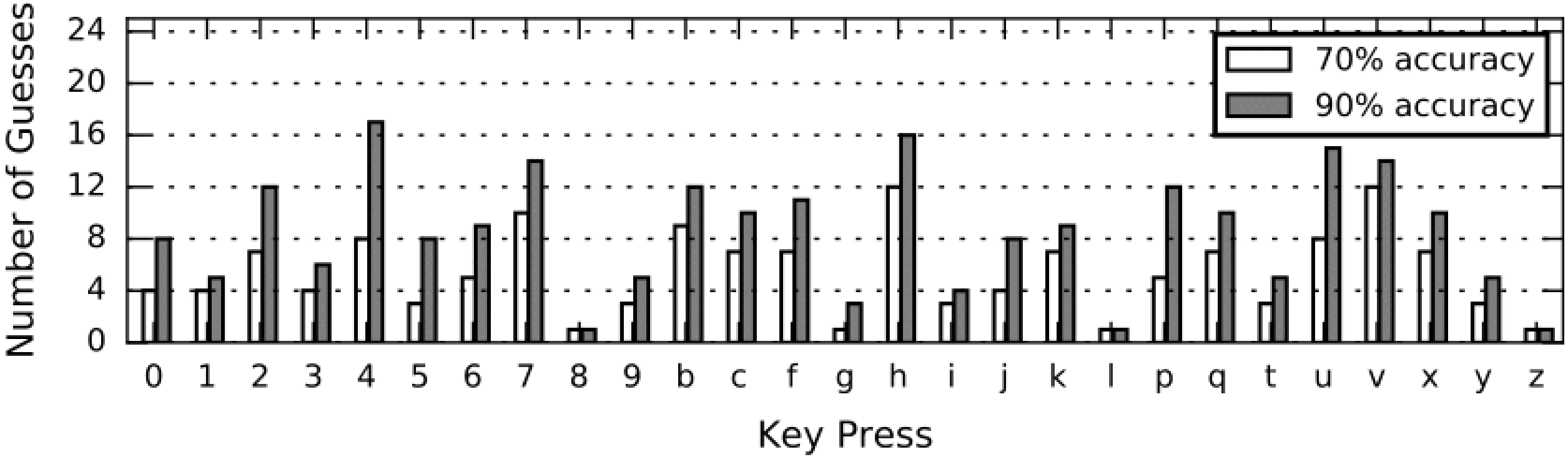
- Huawei Nexus 6P. Android 8.0
- Flush+reload => Evict+reload
  - Resolution 20x lower than Intel
- Pre-render triggered only once

#	Library	Function
1	libskia.so	SkScalerContext_FreeType_Base ::generateGlyphImage
	libskia.so	SkMask::getAddr
2	libskia.so	SkGlyph::computeImageSize
	libskia.so	SkAAClipBlitter::~SkAAClipBlitter



Attack 2: CapitalOne

- Augment 1: 10 logins



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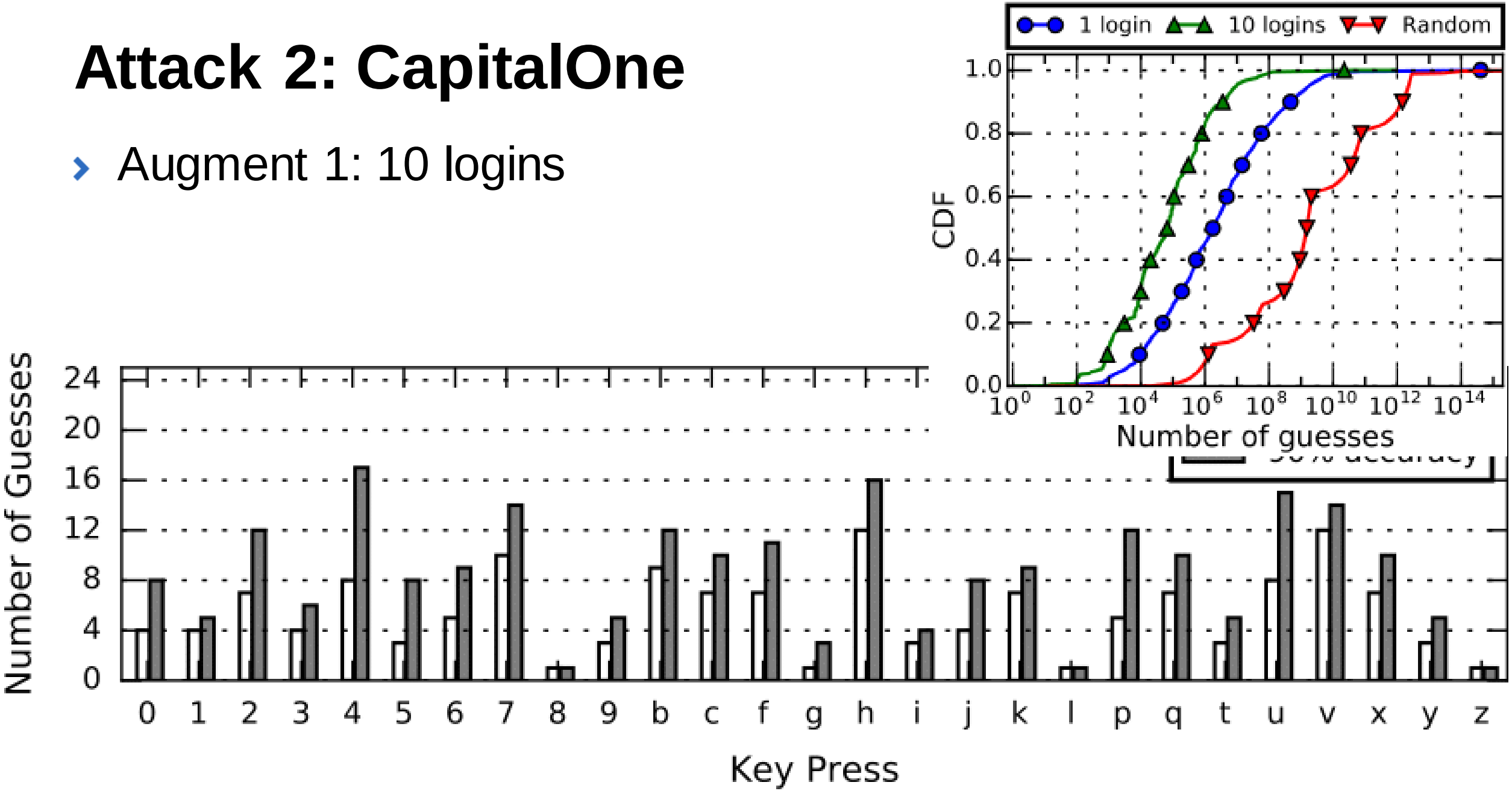

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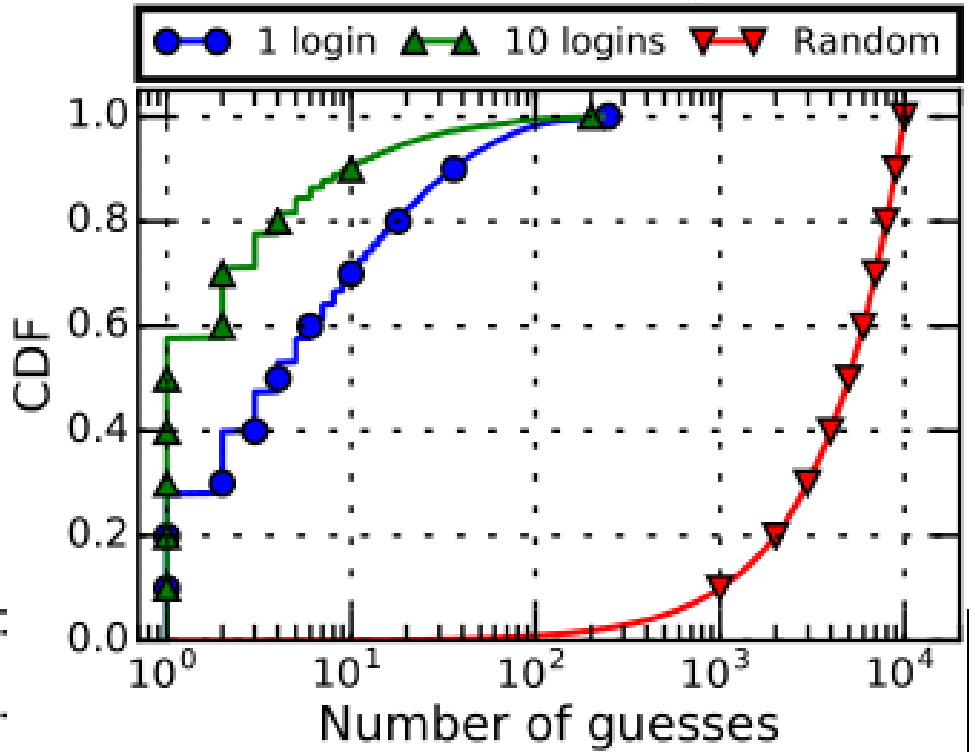
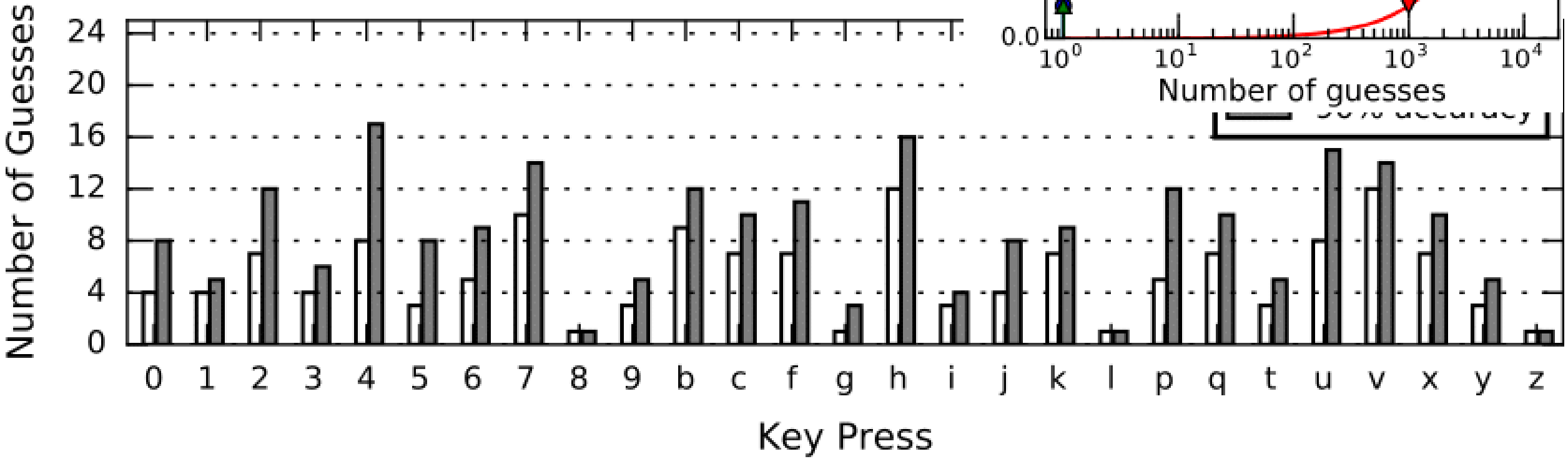
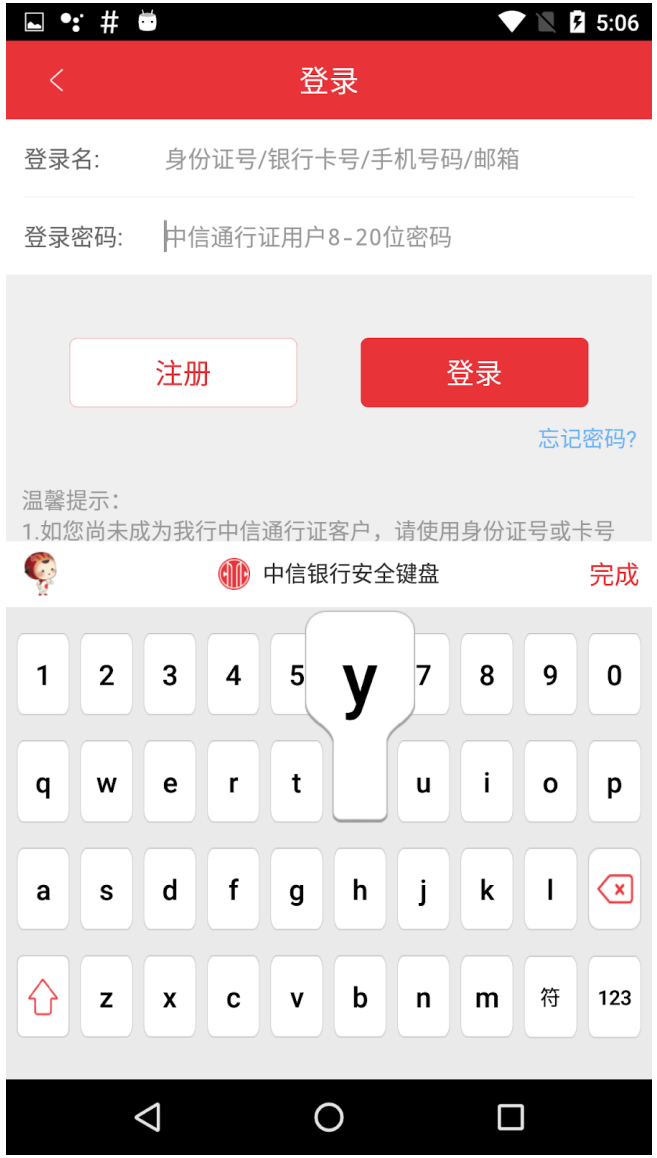
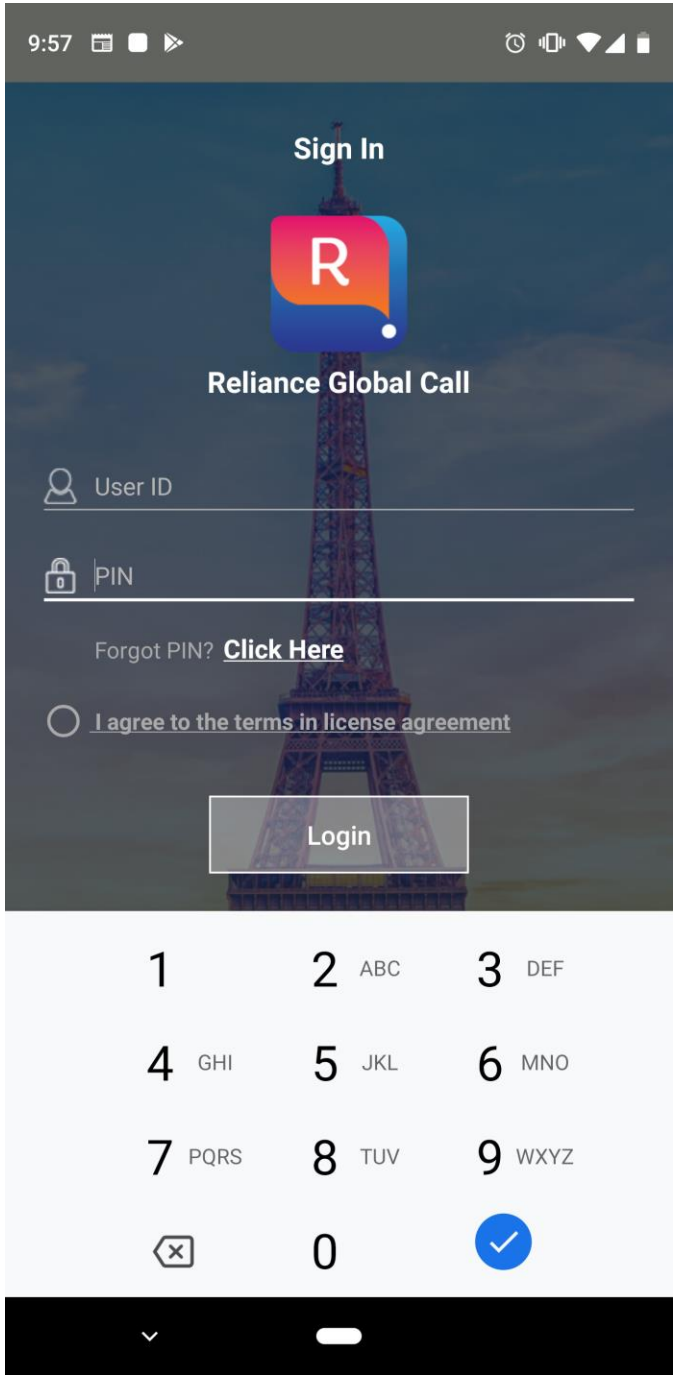
- Augment 1: 10 logins
- Augment 2: Dictionary





Other Apps


5:06
登录
登录名:
身份证号/银行卡号/手机号码/邮箱
登录密码:
中信通行证用户8-20位密码
注册
登录
忘记密码?
温馨提示:
1.如您尚未成为我行中信通行证客户，请使用身份证号或卡号
中信银行安全键盘
完成


9:57
Sign In
Reliance Global Call
User ID
PIN
Forgot PIN? Click Here
I agree to the terms in license agreement
Login

Discussion

- Measurement challenge
  - Measurement resolution
- Extensions
- Mitigations

Discussion

- Measurement challenge
- Extensions
  - Inter-keystroke timing
  - Combining with other side-channels
  - Examine other libraries
- Mitigations

Discussion

- Measurement challenge
- Extensions
- Mitigations
  - Prevent flush+reload
  - Constant-time rendering

Conclusion

- Effective execution time measurement
- Exposing side-channels in graphics libraries
- Evaluations on real-world applications
- Acknowledgement
  - U.S. Army Research Laboratory Cyber Security Collaborative Research Alliance

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Thanks!

Q & A