The Exploit Development Lifecycle

From Concept to Compromise

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BSides Canberra 2024

whoami?

- aka chompie
- Reverse engineer, vulnerability researcher, exploit developer, post exploitation developer
- Head of Vulnerability Research and Exploit Development, IBM X-Force
- ~7 years in offensive security
- Professional poster & Pwnie Award Winner

weird machine mechanic

Overview

The **What** and the **Why**?

1 **Misunderstood**

Exploit development is typically misunderstood

2 **Bugs vs Exploits**

0days get all the attention but it is really **exploit development** that **gives bugs their power**

3 **POC to Production**

A lot of preparation is required for **production use-cases**

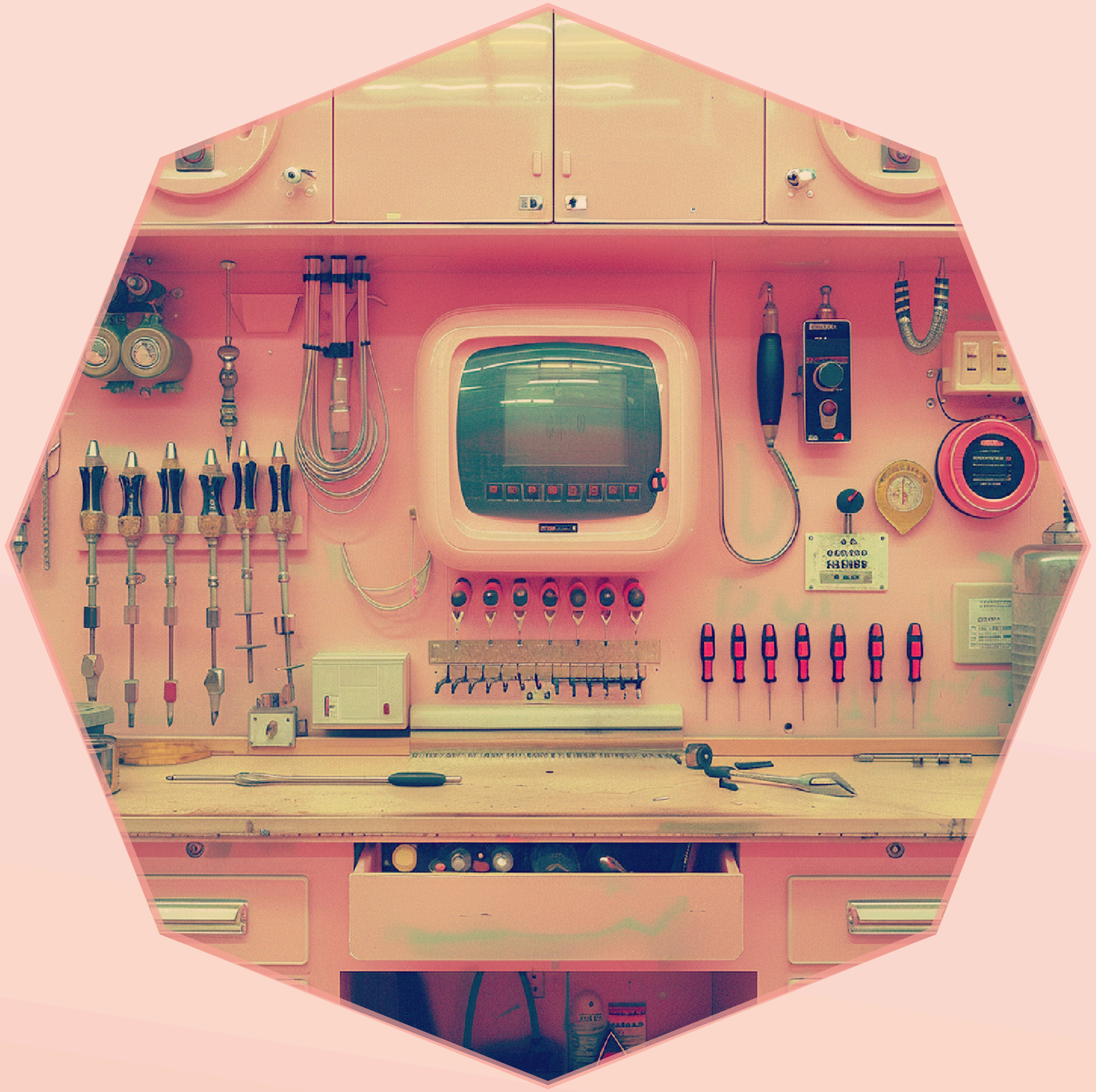
4 **Lifecycle**

Unique **insights** into overseeing the **full exploit lifecycle**: From bug discovery to usage in sophisticated environments

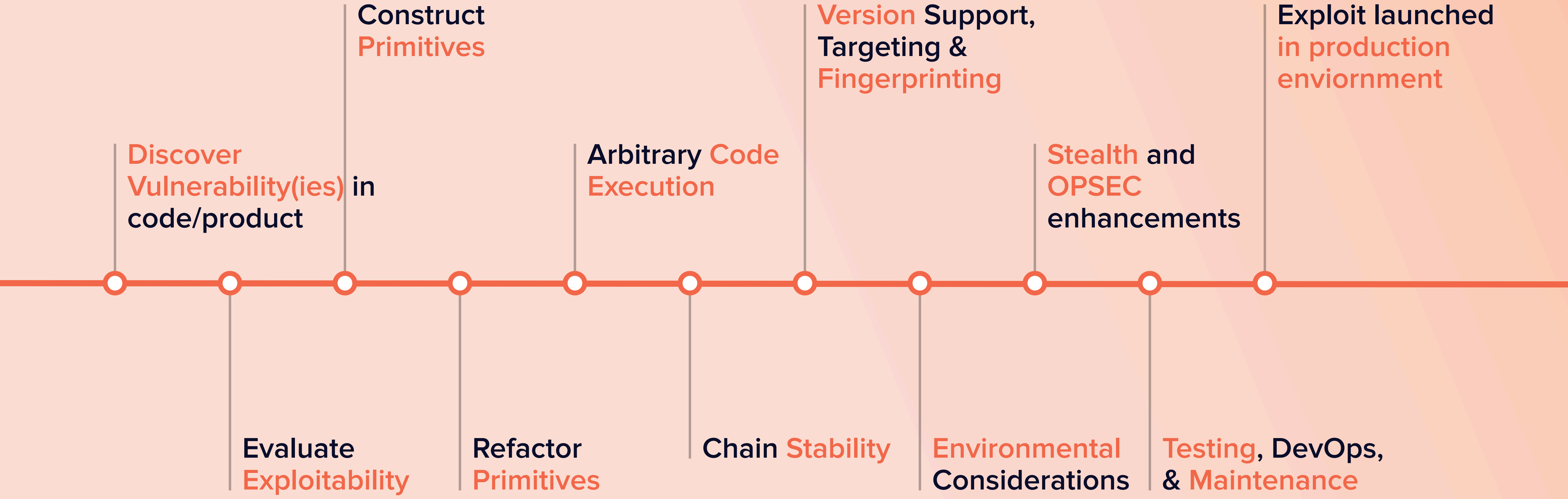
“**Exploit (n)** : A method or piece of code that **leverages vulnerabilities** in software, networks, operating systems, or hardware to **trigger behaviour not intended** by the original designer or developer”

Exploit are ~~Found~~ Built

- The distinction is important
- Finding a vulnerability is a small part of the work
  - Finding the bug
  - Analysing the platform
  - Availability of research labour
  - Doing the hard development and testing work
- This does not even factor in specific target environment considerations (e.g. EDR stack)
- Exploits are code, just like anything else

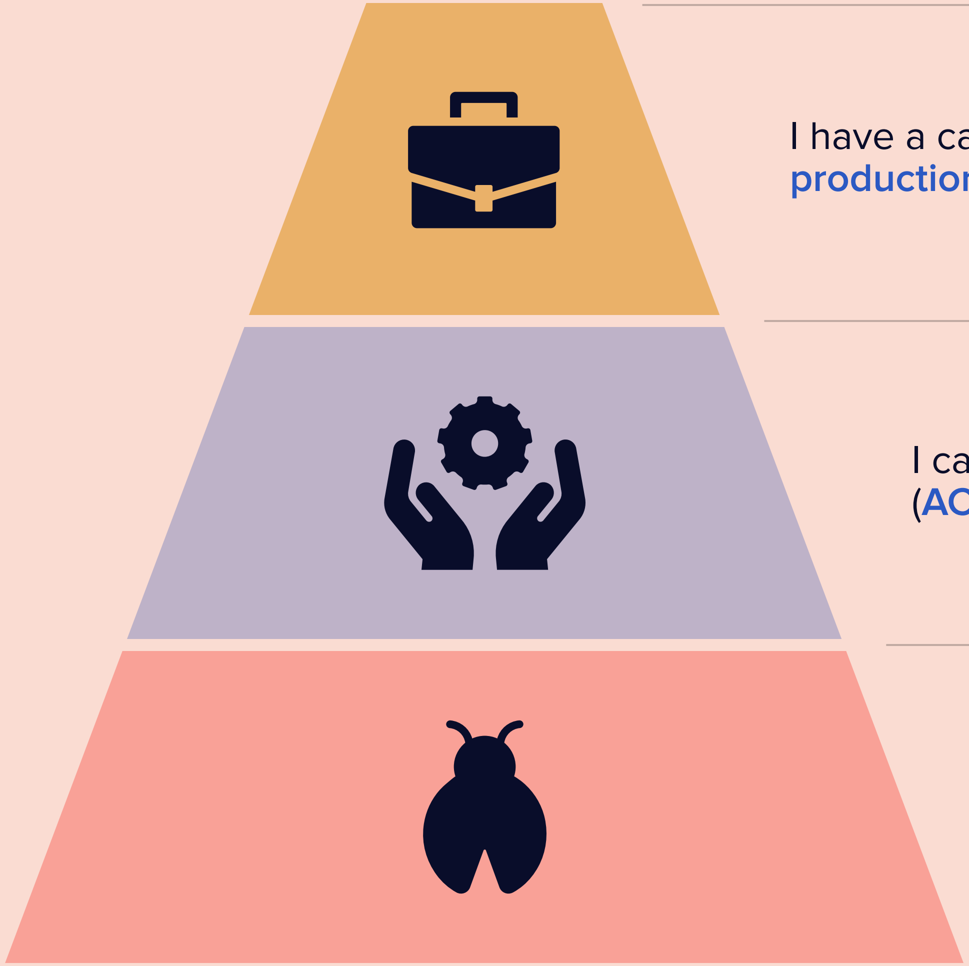


Exploitation Timeline



Not all Exploits are Equal

Various formats and degrees of **quality for deliverables**

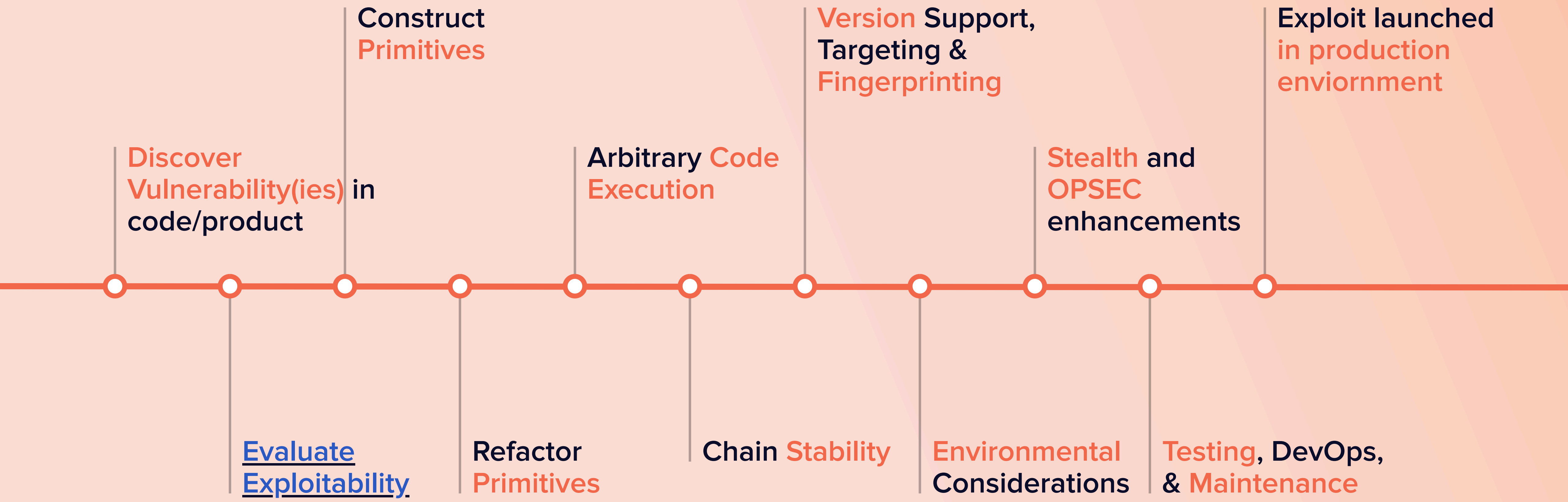


I have a capability to can be **deployed** in a **variety of tested production configurations** with predictable outcomes

I can turn this behaviour into **arbitrary code execution** (**ACE**)

I have a bug and I can trigger **unexpected program behaviour**!

Exploitation Timeline



Evaluating Exploitability

Good bug
Bad bug

I promise this talk is not about bugs

- Software vulnerabilities produce exploit primitives
    - Primitives form generic building blocks for the exploit
- Vulnerabilities should be evaluated by the type of primitive they grant
    - Bad bug == Bad/Non-useful primitive

Evaluating Exploitability: Initial Primitives

Is the bug a good bug?

- Vulnerabilities are non-uniform
- Many variables determine the usefulness of the primitive
- The variables involved depend on the nature of the vulnerability

Vulnerability Properties

Some things to consider

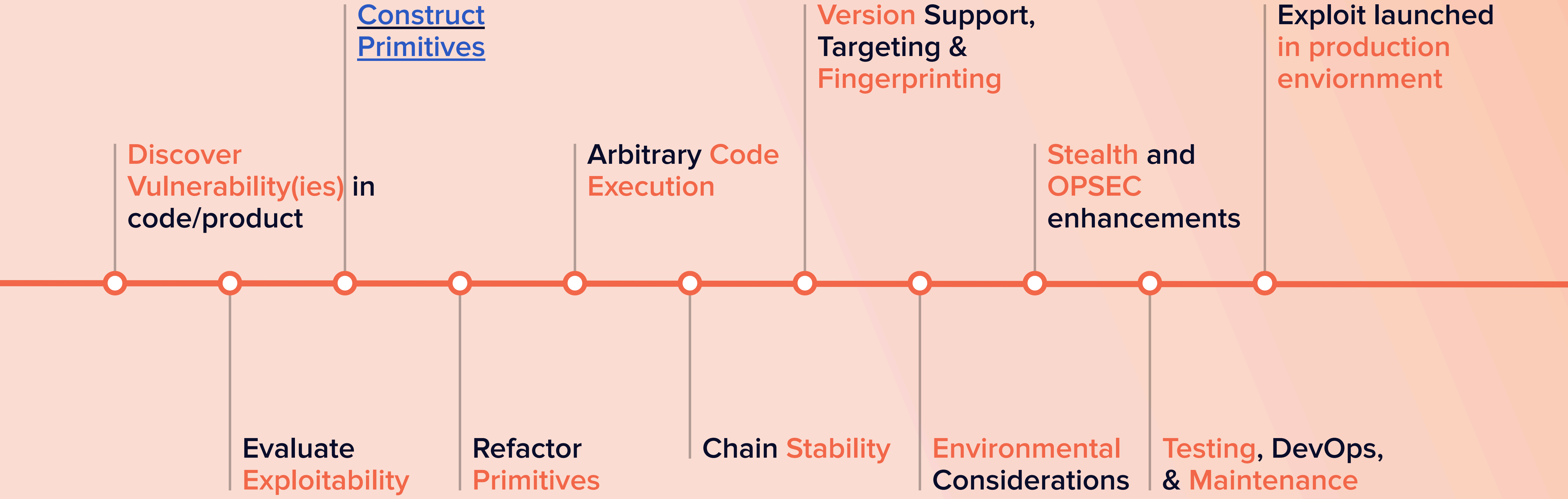
- **What can I influence, where, and how?**
  - Bit flipping at a static offset is less useful than a controlled write at a controlled offset
  - Some weaker primitives can be turned into stronger ones (e.g. out-of-bound read)
- **Repeatability**
  - Does this require **single-shot** exploitation **or** can the bug be **retriggered** to expand the primitive
- **Exploit Mitigations**
  - Don't **prevent bugs**, attempt to **thwart primitives**
  - May render seemingly **strong primitives ineffective**

Evaluating Exploitability is a Cost/Risk Assessment

Betting research time against the reward

It is challenging to make definitive claims about non-exploitability

Exploitation Timeline



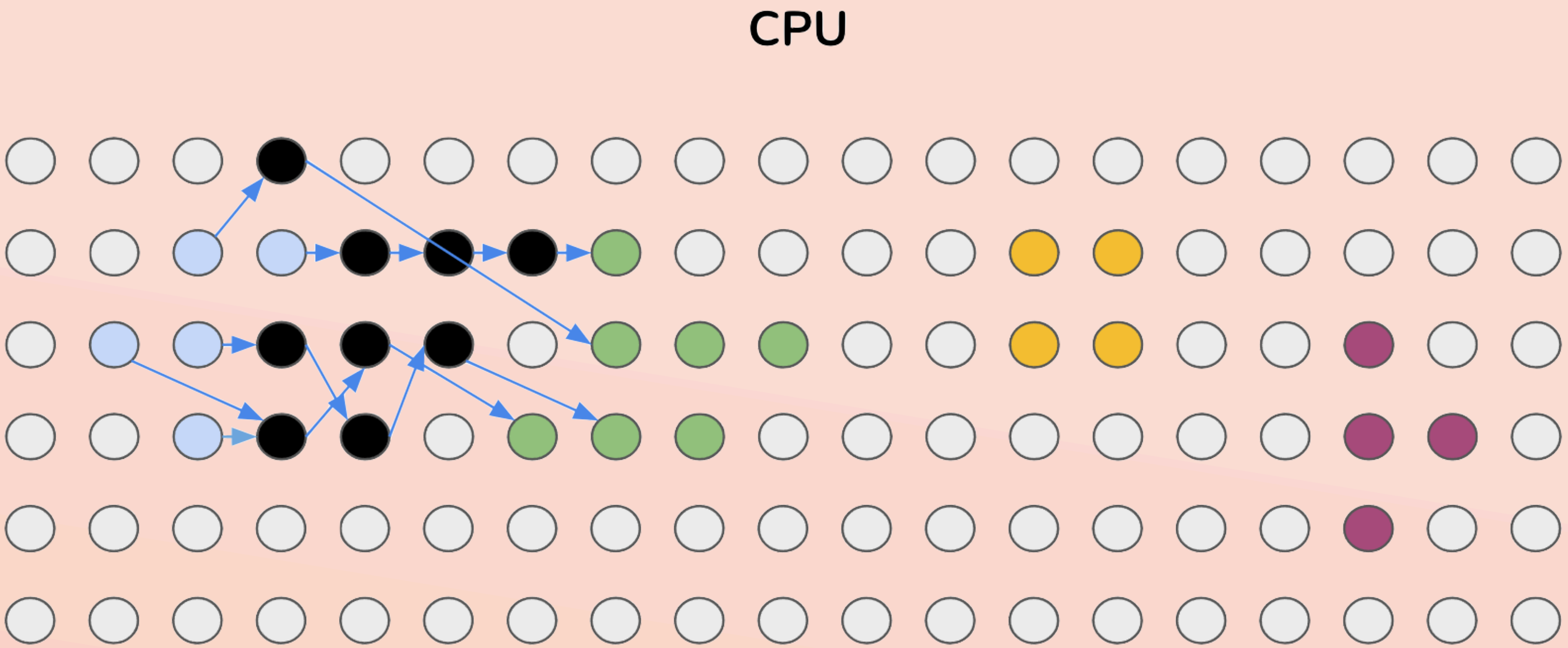
Exploit Construction:

Constructing Primitives

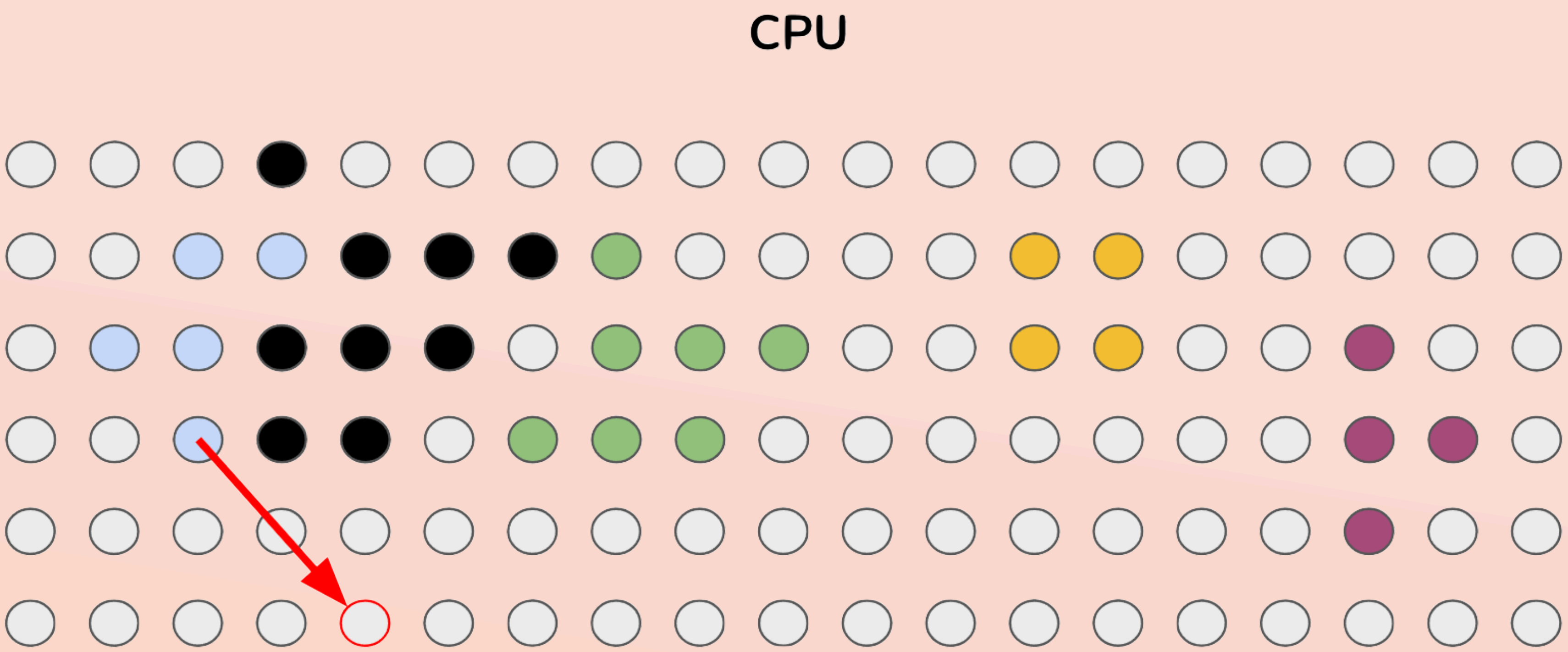
Triggering a **bug** causes the system to **transition from** a **normal machine** (execution follows only expected patterns) **to** a **weird machine** (execution follows patterns outside the specifications of the program)

CPU
State Space

Limiting Weird Machines by Halvar Flake

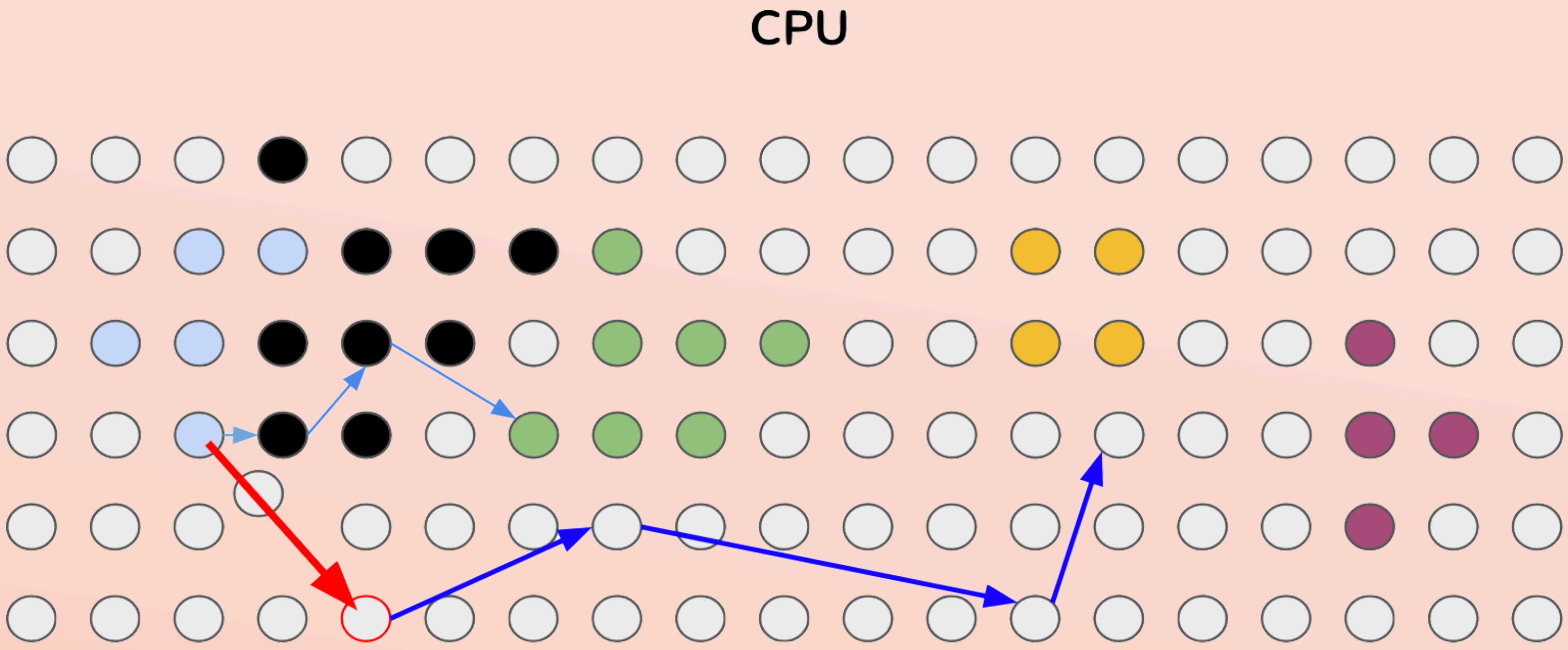


Weird
Machines



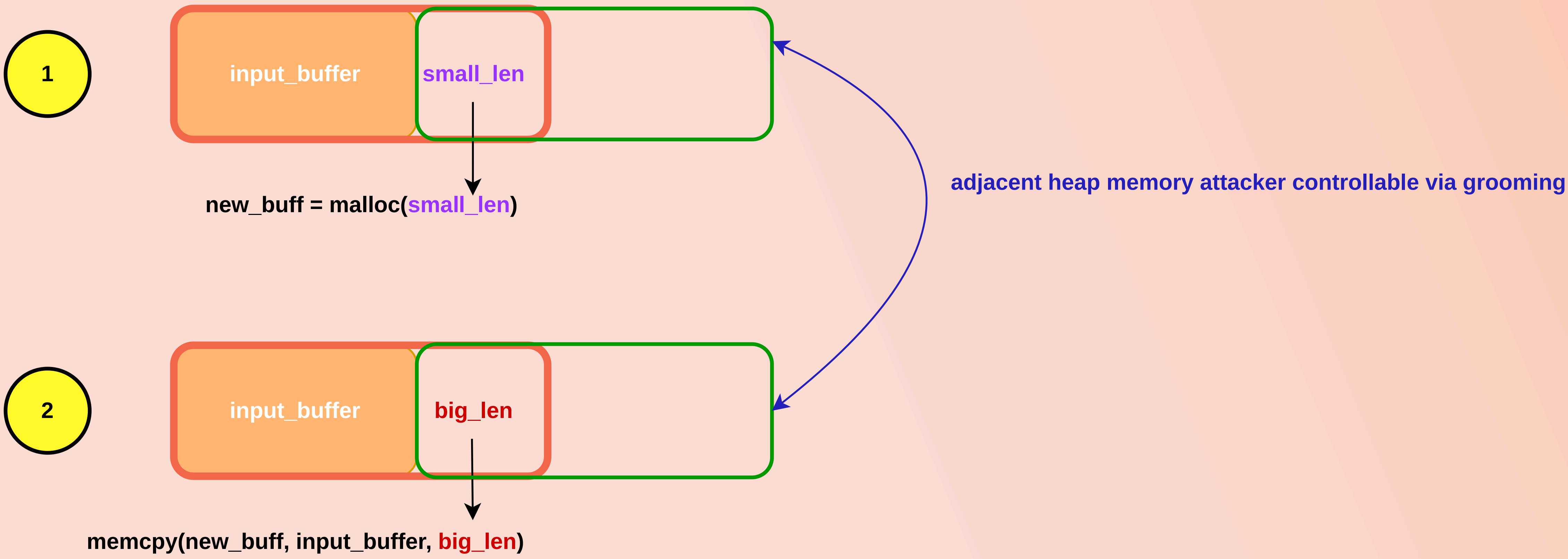
Weird Machine Connectivity

- How close to Turing complete
  - What types of atomic operations can we perform using undefined application behaviour?



Constructing Primitives

ex: Out of Bounds Read ➜ Out of Bounds Write



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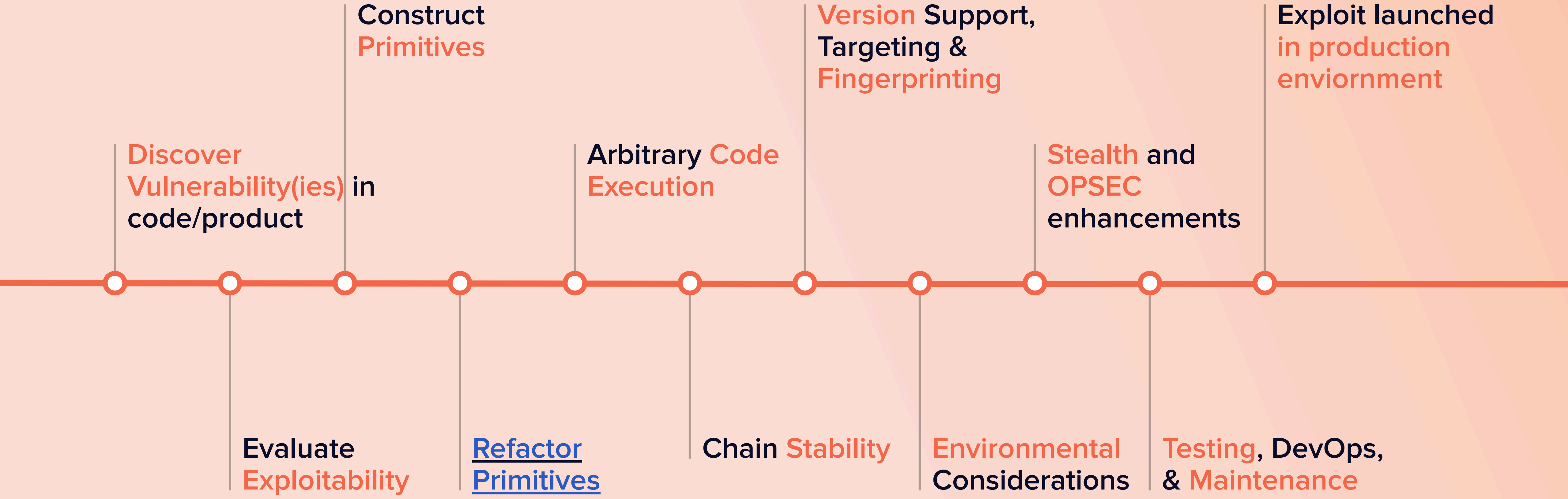
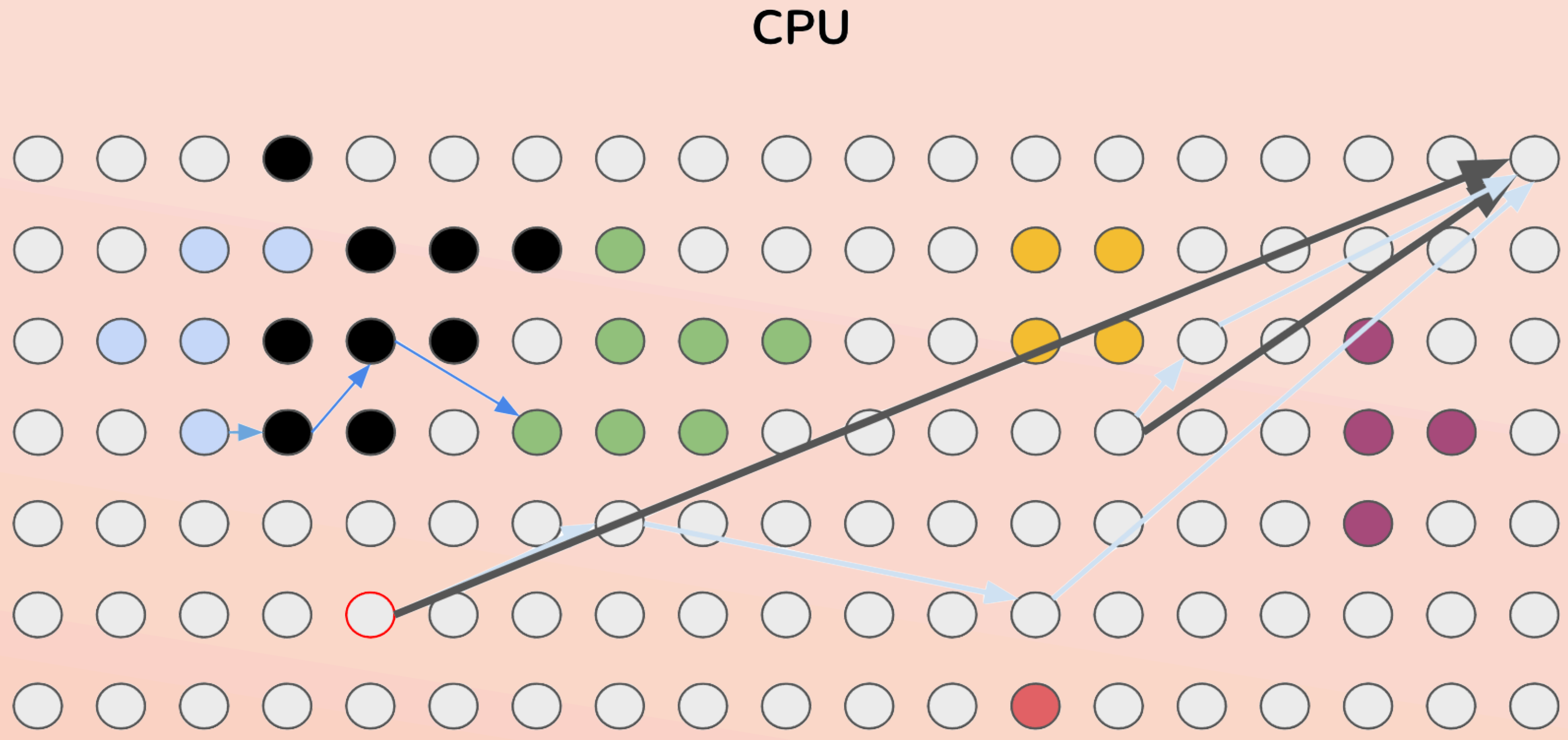


Exploit Construction:

Re-Factor(Construct) Primitives

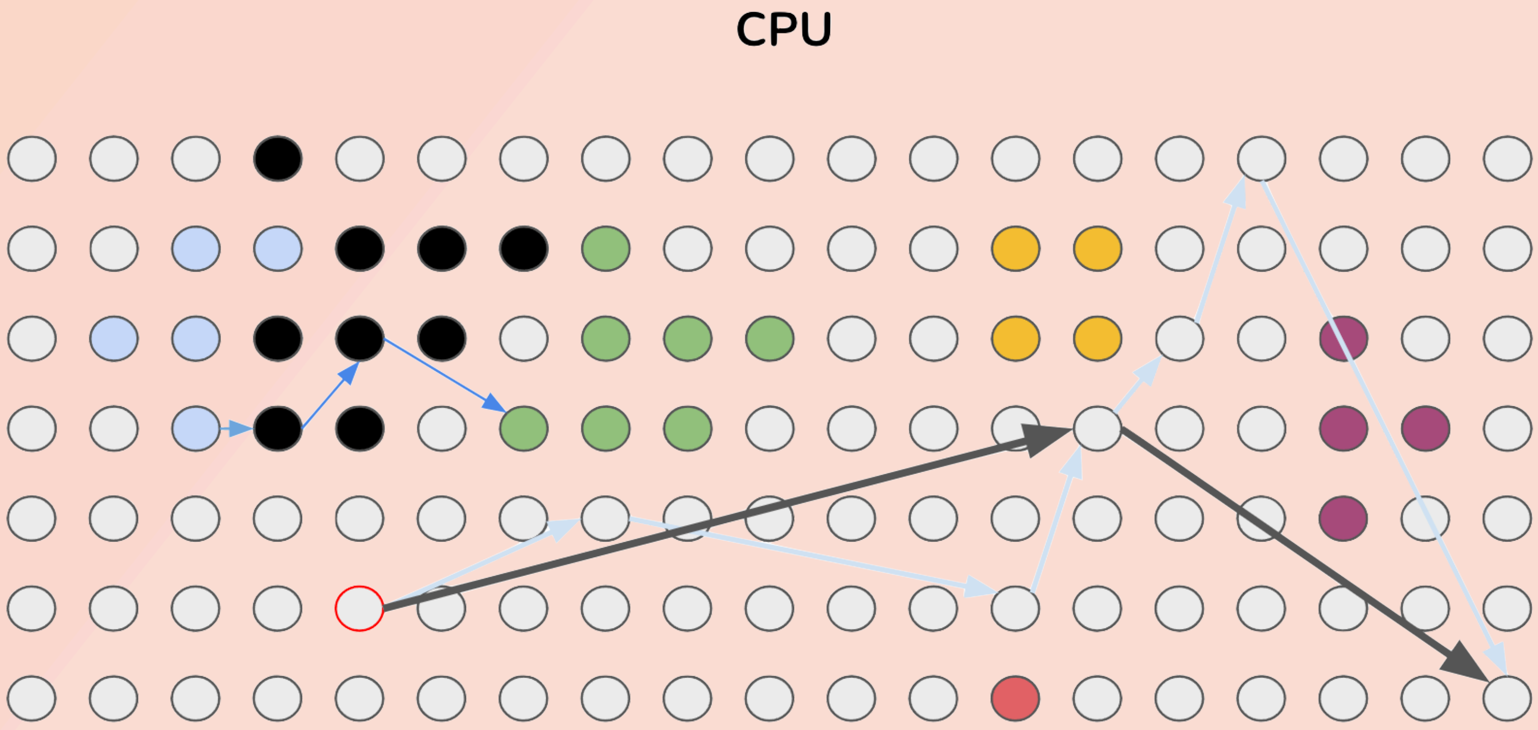
Exploit Mitigations

- **Reduce the number of reachable states from a weird state.**
  - Ex: Address authentication mitigations bends many edges to SEGFAULT state



Mitigation Bypass

- **Mitigations require contortion of primitives**
  - Adds additional steps (state transitions) to achieve stable arbitrary code execution
- **In some sad states, this could possibly be the end of the road**
  - Why Initial target assessment is so important



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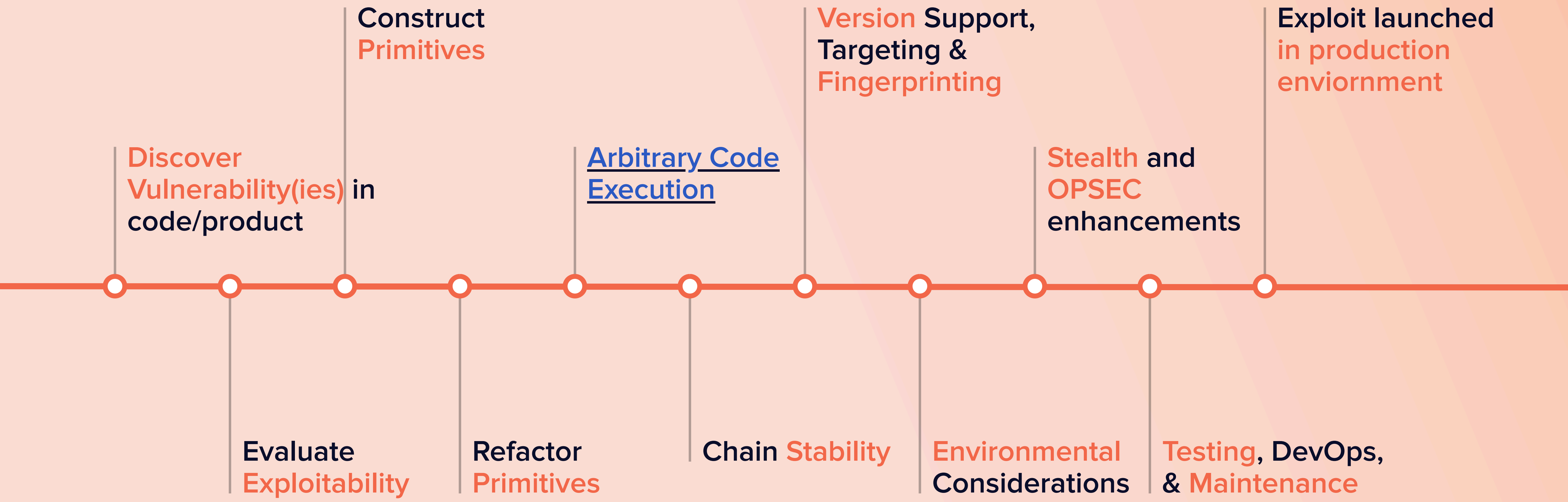


Exploit Construction:

Arbitrary Code Execution

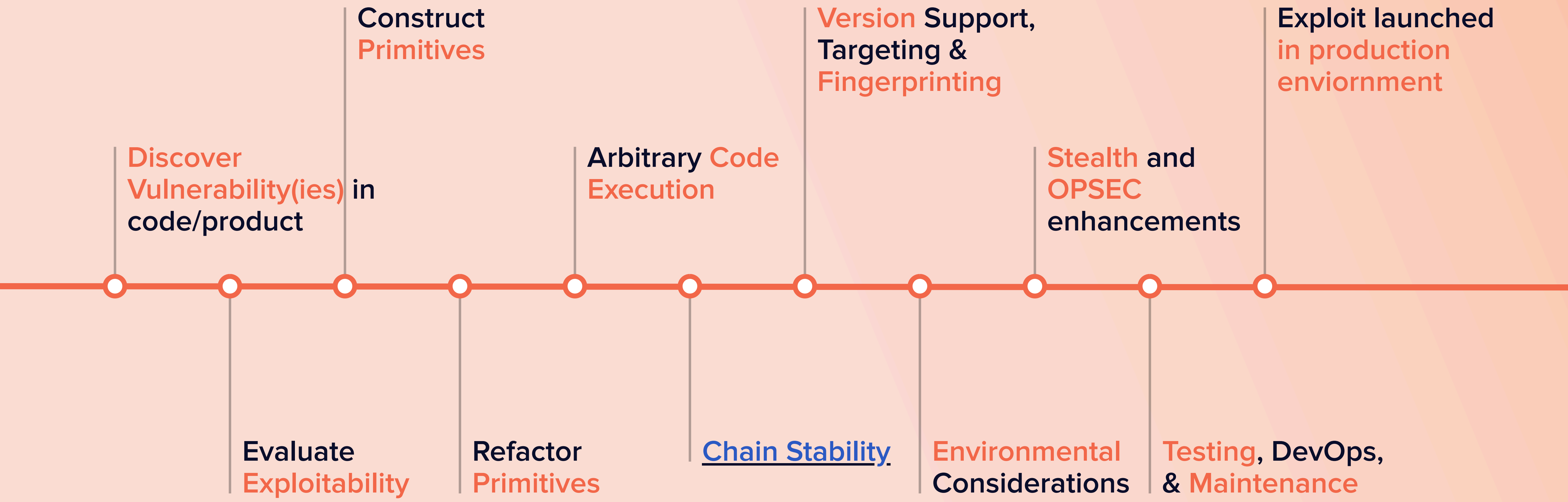
Putting it all together

- Integrating exploit primitives together to achieve arbitrary code execution
- Multiple bugs can be chained together to supplement primitives
- Turing Complete Weird Machine

Recap

- Bug or crash identified
- Viability assessment
- Build primitive chain
  - Rebuild chain as requirements/restrictions change
- Execute weird machine
- Arbitrary Code Execution (ACE) ➡ Most public PoC's stop here

Exploitation Timeline



Exploit Construction:

Chain Stability

Exploits are not always deterministic

Why are live exploit code demos so tense?

Things can go wrong!

Exploit Reliability

- Sometimes depends on the nature of vulnerability
  - Could require getting system into a particular state to trigger vulnerable code path
  - Winning race conditions
- Mitigations can impact exploit stability
  - Some mitigations introduce randomness
  - Can introduce conditions that thwart individual exploitation attempts
- The goal is to increase exploit reliability to 100%
  - s.t. one trigger guarantees successful exploitation

Methodology

- **Primitive Refinement: Examples**
  - Tighten race windows
  - Add precision to sprays for vulnerable object allocation
  - Groom memory to predictable layout
  - Swapping objects in sprays
  - Find better program gadgets

- **Developing new primitives**
  - Layer primitives to create new capabilities
  - E.g. oracle primitives to bypass randomness mitigations

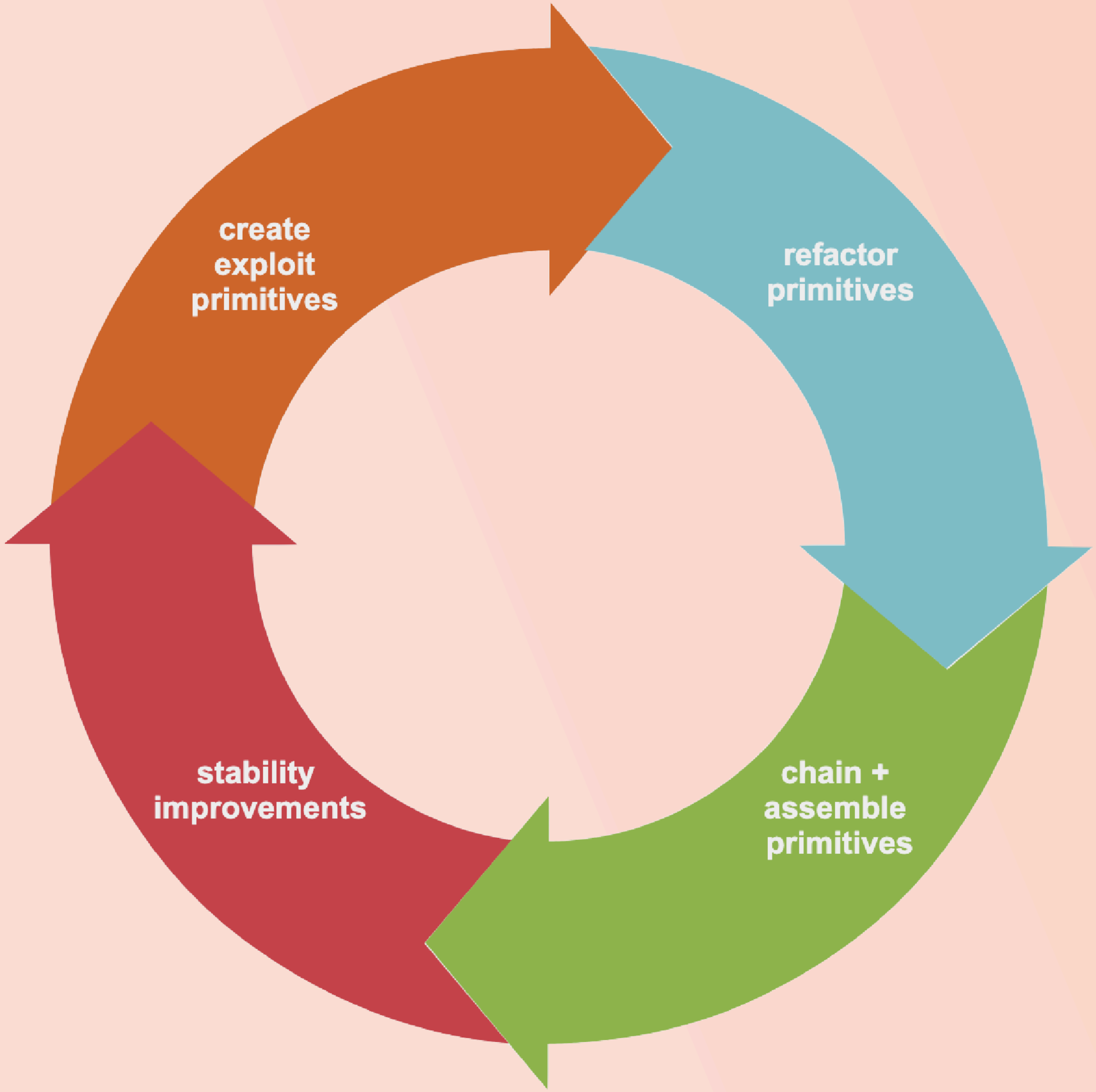
- **Analyze program control flows + refactor exploit code to address the observed, known, possible weird machine states**

Clean-up

- **Release used resources**
  - Destroy objects
  - Free memory
  - Close handles
- **Is continuation a problem?**
  - Does the system behave normally, post exploitation?
- **Minimize exploit side-effects**
  - Restore to original pre-exploitation state (as much as is possible)

Round and Round

The cycle goes on



Exploitation Timeline

1. Discover Vulnerability(ies) in code/product
2. Evaluate Exploitability
3. Construct Primitives
4. Refactor Primitives
5. Arbitrary Code Execution
6. Chain Stability
7. Version Support, Targeting & Fingerprinting
8. Environmental Considerations
9. Stealth and OPSEC enhancements
10. Testing, DevOps, & Maintenance
11. Exploit launched in production enviornment

Real-world Deployment: Version Support

It works on my machine!

- The more targeted your code, the better
- Variances across targets can happen in many areas
  - Types of objects and object sizes
  - Implemented program features
  - Offsets, signatures
  - Available gadgets
  - Drastic differences in program logic
  - Implemented/supported exploit mitigations
- Broad production targeting means you have to deal with more variance

Real-world Deployment:

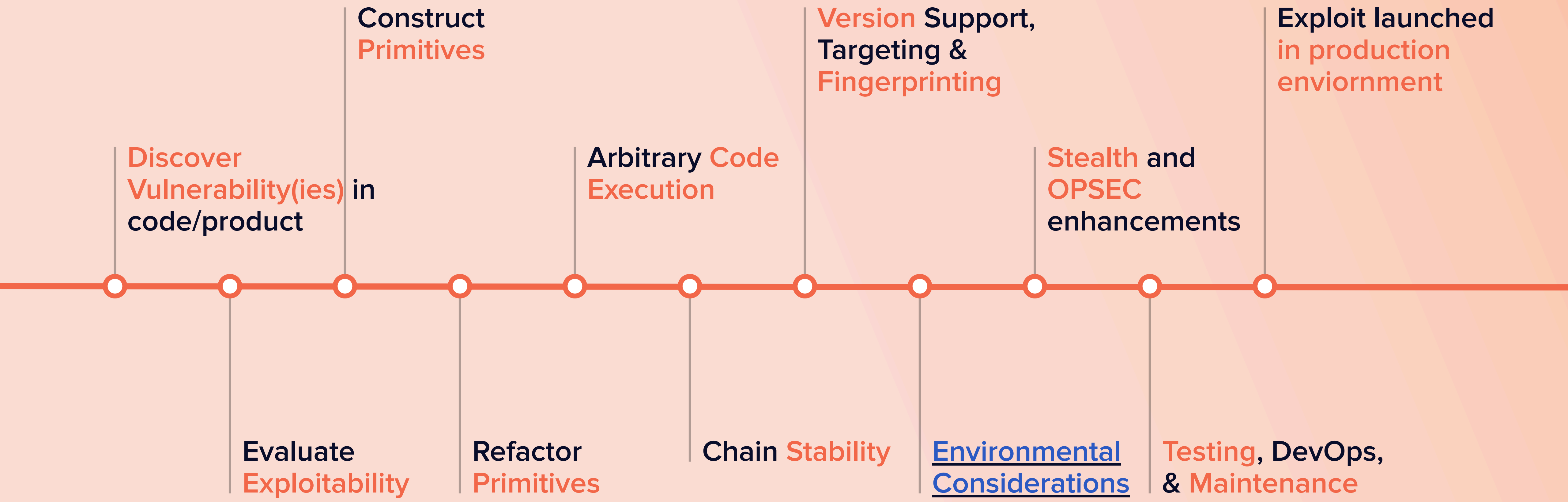
Targeting & Fingerprinting

Situational Awareness

Is the exploit self aware?

- Targeting engine
  - Local fingerprinting
  - Remote fingerprinting
- Exploitation may vary not just based on software and OS version but also on hardware
- How will the exploit know which version of the chain should be used?
  - In-memory pattern matching
  - API call return information
  - System files (e.g. file build version numbers)
  - Service response metadata
  - Staged deployment?

Exploitation Timeline



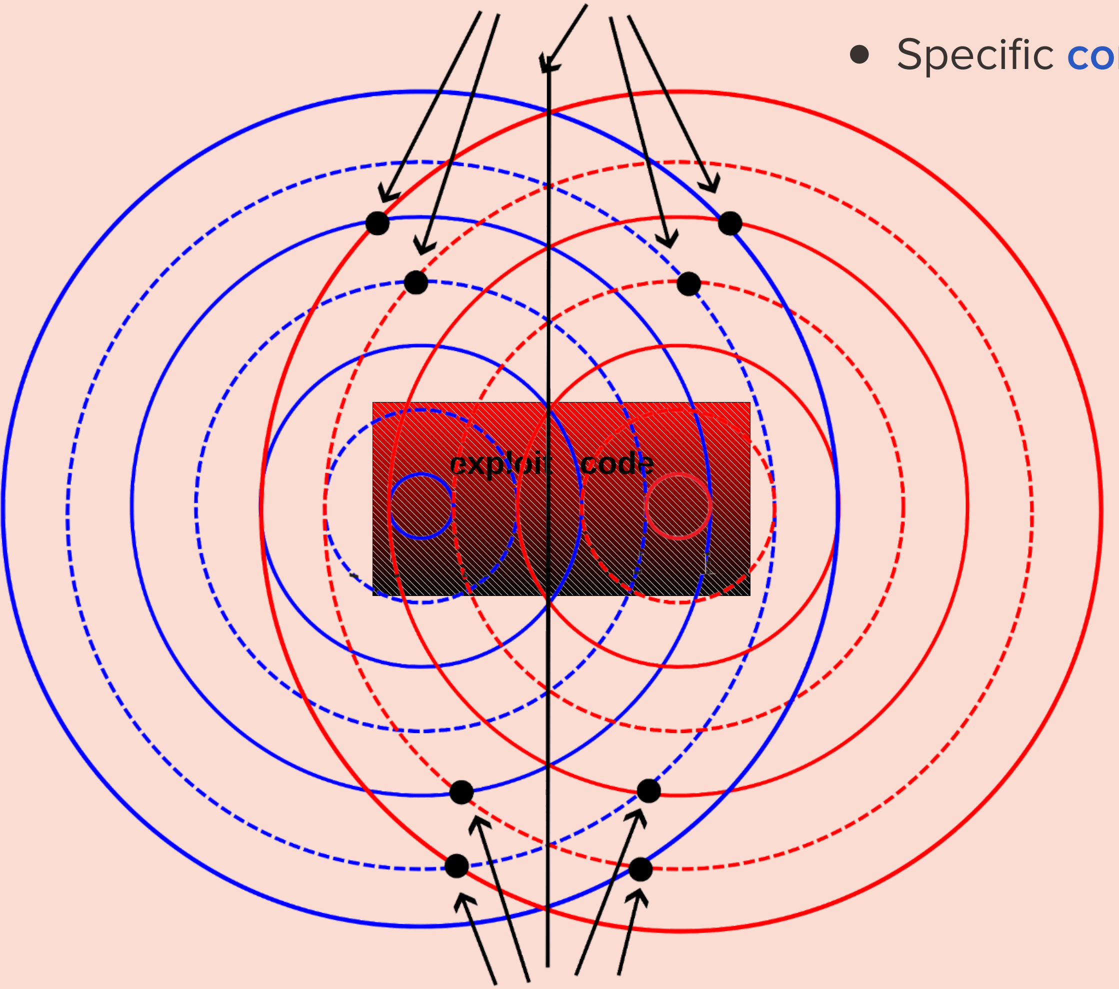
Real-world Deployment: Environmental Considerations

Exploits in the Real World

A lot can go wrong

- Real life systems are hard to emulate
- The more details you have about the target the better
  - By closely emulating the target environment can anticipate what can go wrong beforehand
- Can try to approximate real systems by creating inorganic system noise
  - performance testing tools, stress tests in development kits

Exploits in the Real World

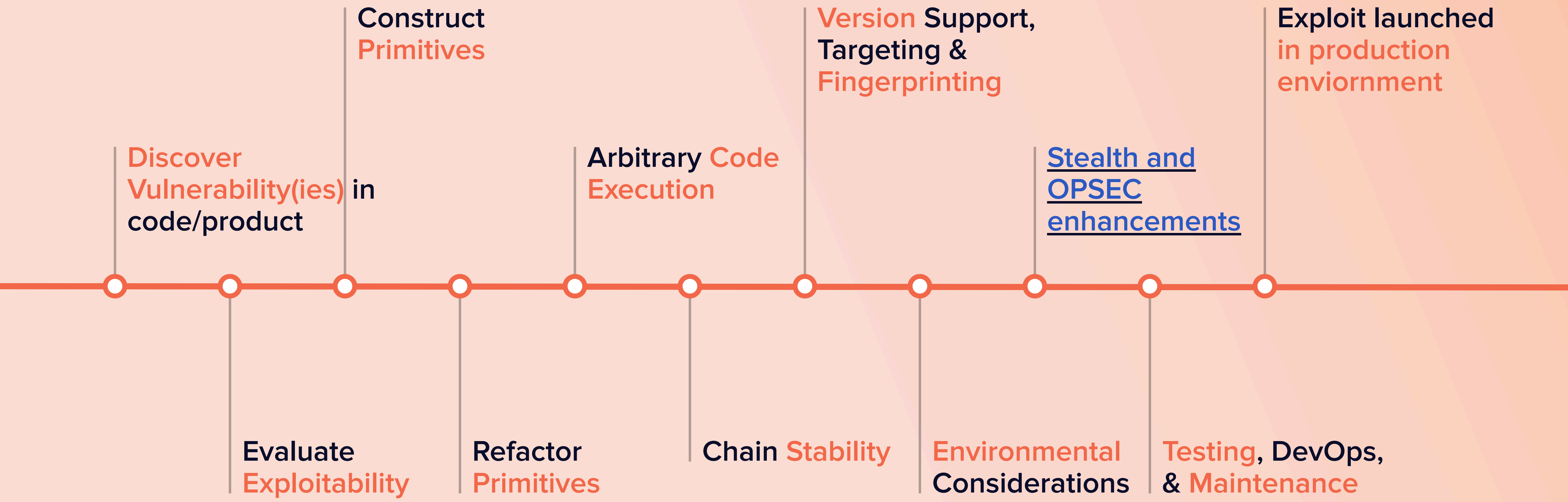


- System load can affect reliability
  - Network traffic and running programs can use resources that interfere with exploit
  - Specific configurations can also interefere

- Hardware, network traffic, system noise

- Low resource environment vs High resource environment
  - E.g. successfully exploiting race conditions requires a minimum core count

Exploitation Timeline



Real-world Deployment: Stealth Mode

Protect Your Work

- **Relevant for private chains**
  - Exploits that can be burned
  - Unlike public disclosure and PoC's or competitions like Pwn2Own and TianfuCup
- **In The Wild exploits ↘ Detection Technology ↘**
  - Need to blindly anticipate detection strategies
- **Knowing your target is crucial, know what you're up against**
  - EDR labs and simulated environments
    - Offline Labs are tricky
    - Specific EDR configurations can impact detection/behavior
  - Valuable targets may be monitored by solutions not available to the public

Don't Get Caught

Other steps of x-dev cycle come into play here!

- **Stability, can the exploit crash?**
  - **Crash dumps** are crucial in **forensics**, they could give the bug away completely
  - Clean-up, **does the system run normally** after exploitation? Does it **release all resources**?
- **Exploitation primitives, are they known? Signatured?**
  - **Bugs** triggers by themselves and are **hard to anticipate**, consequently **less likely to get caught**
  - Exploitation **side effects** easier to **signature**, consequently more **likely** to **get caught**
    - Credential overwrites, token swapping, function table pointer overwrites, changing values in important memory
- **Environmental considerations, what is running on the target?**
  - **EDR**, other **adversaries**

Don't Get Caught

Other misc. considerations

- Size?
- Execution Method/Source?
  - executable format?
  - folder path of exploit
- Methods + Prep?
  - calling suspicious APIs?
- Strings?

Bottom Line

- Minimize the unavoidable side effects of exploitation
- Apply forensic counter-measures
- Make it like you were never there

Real-world Deployment: OPSEC Attribution

Not Like Stealth

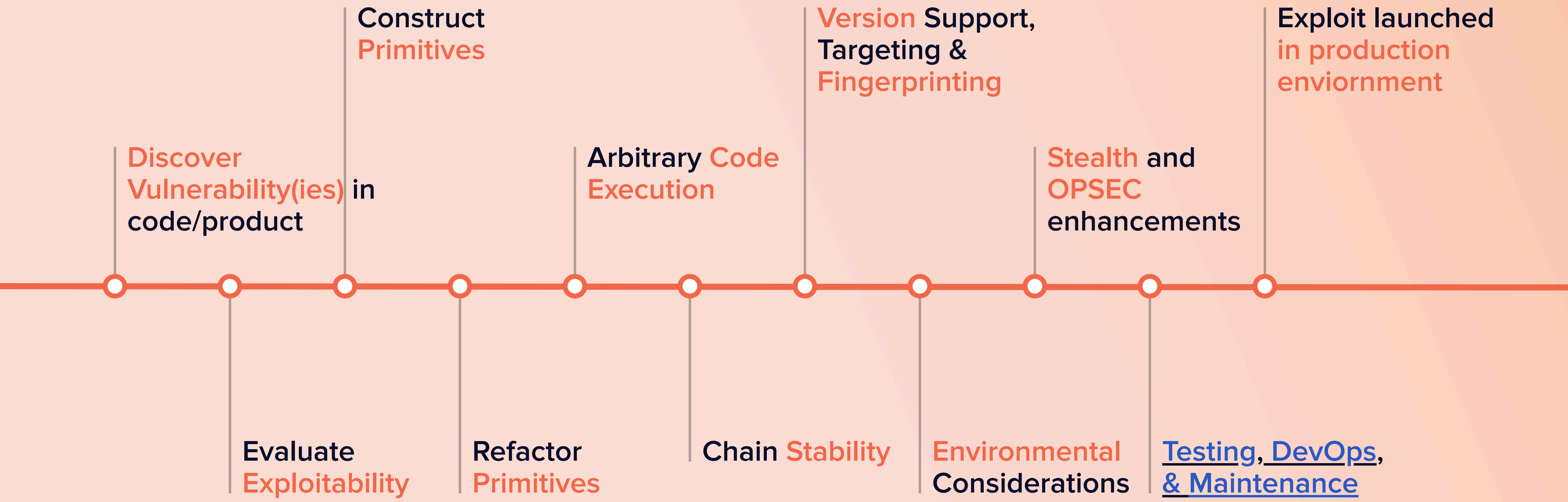
- Stealth is about hiding as best as possible, OPSEC is not so straight forward
- More in line with damage control
- Design decisions at this stage largely depend on the actor and their goals
  - Stakes can be high
  - Certain approaches can be better for some situations vs others
    - Subjective, almost an art form

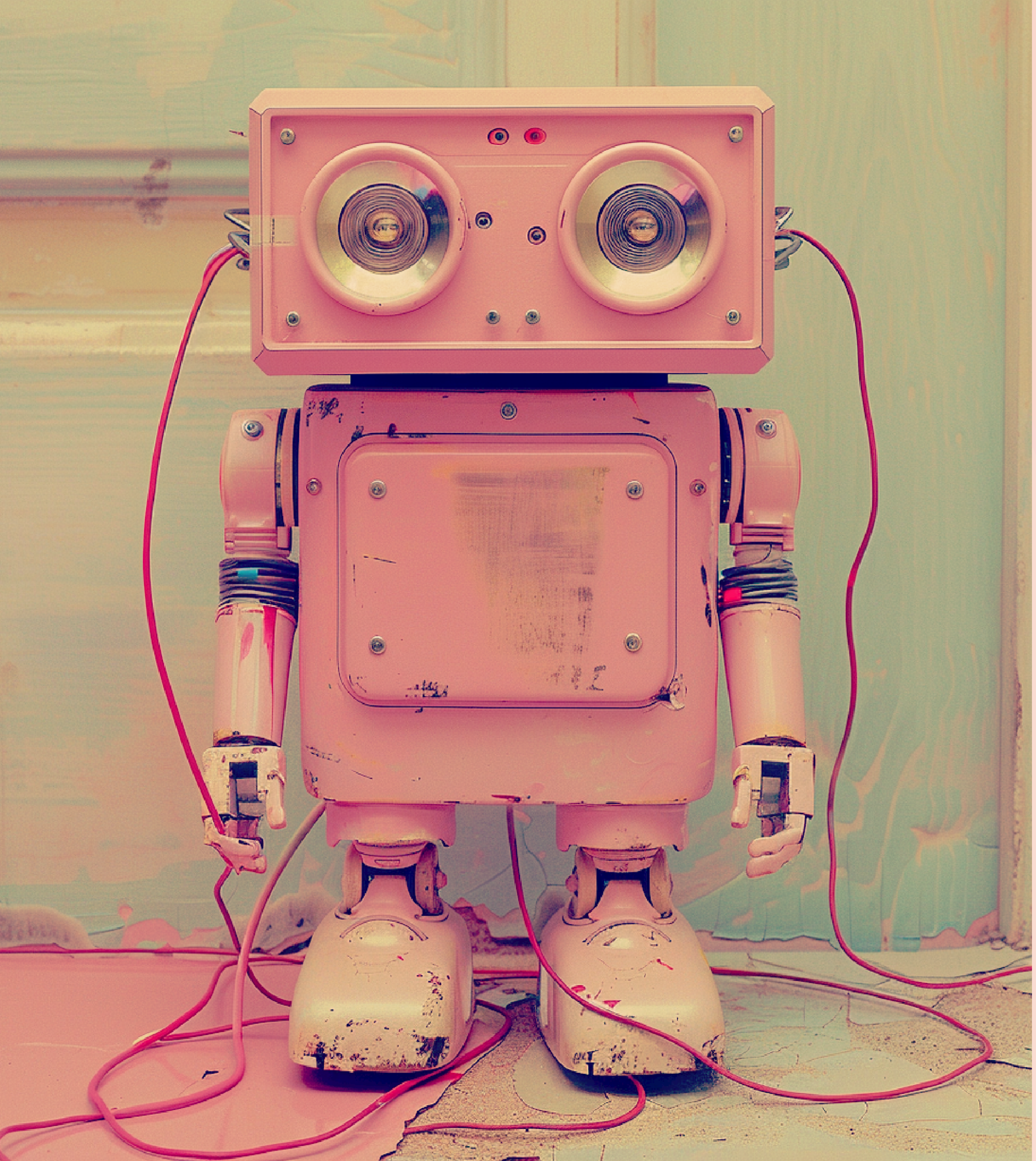
Art

Strategy without tactics is the slowest route to victory. Tactics without strategy is the noise before defeat.

- **Binary artifacts can inadvertently leave behind metadata (e.g. from compilers)**
  - To **strip or not, or fake**?
  - Manipulation to **shift attribution**?
- **Anti reverse engineering & obfuscation**
  - If captured, make it **hard to analyse**, **to reproduce**, or **understand**
  - OR: make it look **innocuous**
- **Techniques & coding styles**
  - **Specific techniques**, primitives and code styles may be **associated with a known threat actor**
- **Minimize what can be burned**
  - Maximizing **novelty** isn't always the **best strategy**
  - **Separate post-exploitation** tooling from the **exploit chain**

Exploitation Timeline





Testing, Maintenance,

& Exploit DevOps Considerations

chompie
@chompie1337

when the offsets change

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Exploits Are Software

- Proper Documentation so operators know how to use it
- Test against all targeted versions & common environmental constraints
  - Unit testing exploit primitives
  - EDR lab
  - Automation and sophisticated DevOps - attackers with more resources have an advantage
- Fixing the toolchain when unexpected situations inevitably pop up
- Keeping up with new OS/software builds
  - Offset custodians 😓

Conclusion: Hug Your Neighborhood Exploit Developer

- Exploit development is its own art, separate from vulnerability research
- A lot goes into weaponizing a bug
  - More targeted, less ambiguity ➡ less guesswork for development
- Complexity of SDLC make it so actors with more resources have a big advantage
  - Sophisticated exploit development is highly skilled work and very niche, very few are doing this for fun or for free
- The bar is high, which is why we rarely see mass exploitation of the critical vulnerabilities found in valuable targets
  - Some exceptions in exceptional circumstances (e.g. EternalBlue, leaked nation-state tooling)

Thank You!

Halvar Flake

Mark Dowd

FuzzySec

wintercoats

The End

Questions?

https://chomp.ie/

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