BitBlaze: Binary Analysis for Computer Security

Dawn Song

Computer Science Dept.

UC Berkeley

Malicious Code---Critical Threat on the Internet

- **Diverse forms**
  - **Worms, botnets, spyware, viruses, trojan horses, etc.**
- **High prevelance**
  - **CodeRed Infected 500,000 servers**
  - **61% U.S. computers infected with spyware [National Cyber Security Alliance06]**
  - **Millions of computers in botnets**
- **Fast propagation**
  - **Slammer scanned 90% Internet within 10 mins**
- **Huge damage**
  - **$10billion annual financial loss [ComputerEconomics05]**

Defense is Challenging

- **Software inevitably has bugs/security vulnerabilities**
  - **Intrinsic complexity**
  - **Time-to-market pressure**
  - **Legacy code**
  - **Long time to produce/deploy patches**
- **Attackers have real financial incentives to exploit them**
  - **Thriving underground market**
- **Large scale zombie platform for malicious activities**
- **Attacks increase in sophistication**

- **We need more effective techniques and tools for defense**
  - **Previous approaches largely symptom & heuristics based**

The BitBlaze Approach

- **Semantics based, focus on root cause:**

  Automatically extracting security-related properties from binary code (vulnerable programs & malicious code) for effective defense

- **Automatically create high-quality detection & defense mechanisms**
  - **Automatic generation of vulnerability signatures to filter out exploits**
  - **Automatic detection and classification of malware**
    - **Spyware, keylogger, rootkit, etc.**
    - **Automatic detection of botnet traffic**

- **Able to handle binary-only setting**

Binary Analysis: Imperative & Challenging

- **Binary analysis is imperative**
  - **Source code is often unavailable**
    - **COTS programs**
    - **Malicious code**
  - **Binary is truthful**
- **Binary analysis is challenging**
  - **Lack higher-level semantics**
    - **Even disassembling is non-trivial**
  - **Malicious code may obfuscate**
    - **Code packing**
    - **Code encryption**
    - **Code obfuscation & dynamically generated code**
- **Need techniques & tools to address these issues**

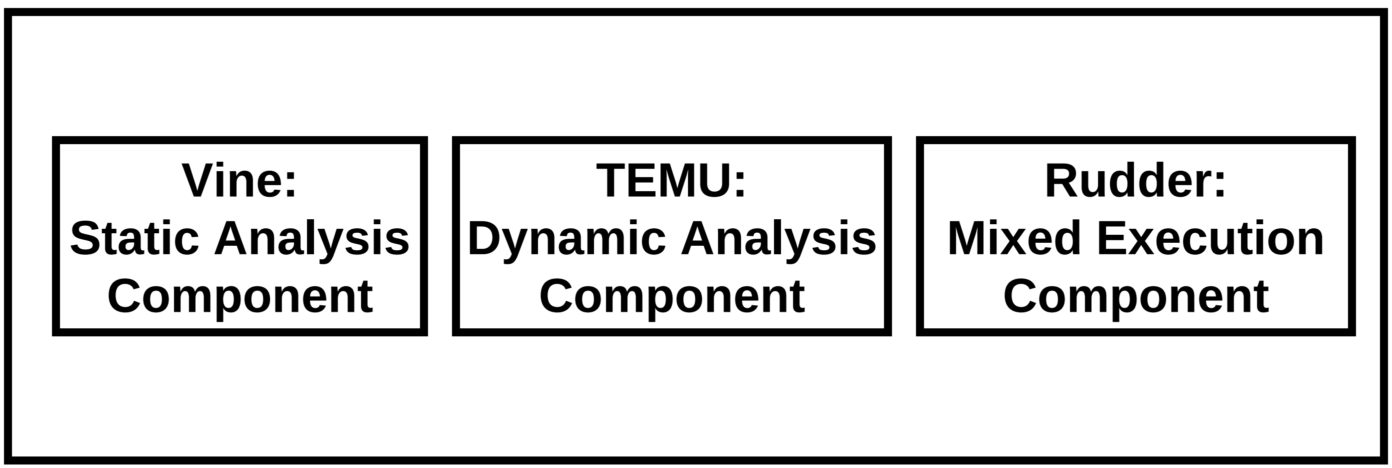
The BitBlaze Vision & Research Foci

1. **Design and develop a unified binary analysis platform for security applications**
   - **Identify & cater common needs of different security applications**
   - **Leverage recent advances in program analysis, formal methods, binary instrumentation/analysis techniques to enable new capabilities**

2. **Introduce binary-centric approach as a powerful arsenal to solve real-world security problems**
   - **COTS vulnerability analysis & defense**
   - **Malicious code analysis & defense**
   - **Other security applications**

The BitBlaze Binary Analysis Platform

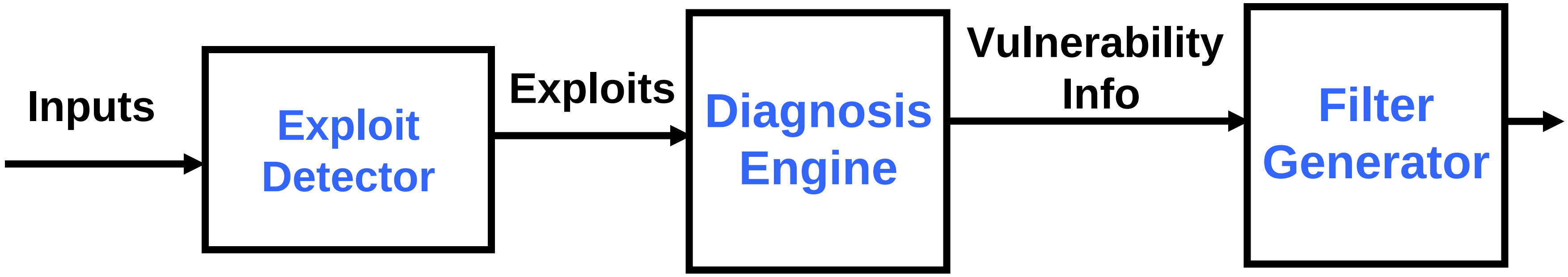
- **A unique infrastructure:**
  - **Novel fusion of static, dynamic analysis techniques, and formal analysis techniques such as symbolic execution**
  - **Vine: accurate static analysis using VineIL (Intermediate Language)**
  - **TEMU: whole-system, fine-grained, symbolic emulation system**
  - **Rudder: automatic exploration of program execution space**



BitBlaze Binary Analysis Platform

BitBlaze in Action: Addressing Security Problems

- **Effective new approaches for diverse security problems**
  - **Over dozen projects**
  - **Over 12 publications in security conferences**
- **Exploit detection, diagnosis, defense**



- **In-depth malware analysis**
- **Others:**
  - **Reverse engineering**
  - **Deviation detection [Best Paper Award]**
  - **Semantic binary diff**

Talk Outline

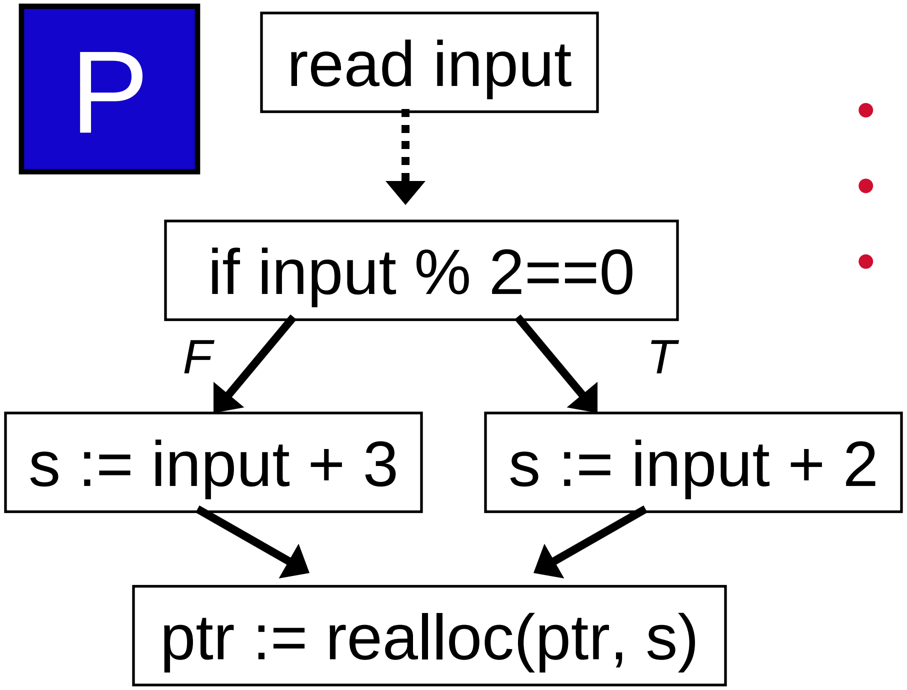
- **Motivating security applications**
  - **Automatic patch-based exploit generation**
- **Components**
  - **Vine: VineIR, static analysis on VineIR**
  - **TEMU: whole-system, fine-grained, symbolic emulation system**
  - **Rudder: automatic execution space exploration**
- **Future directions and conclusion**

Automatic Patch-based Exploit Generation

- **Given vulnerable program P, patched program P', automatically generate exploits for P**

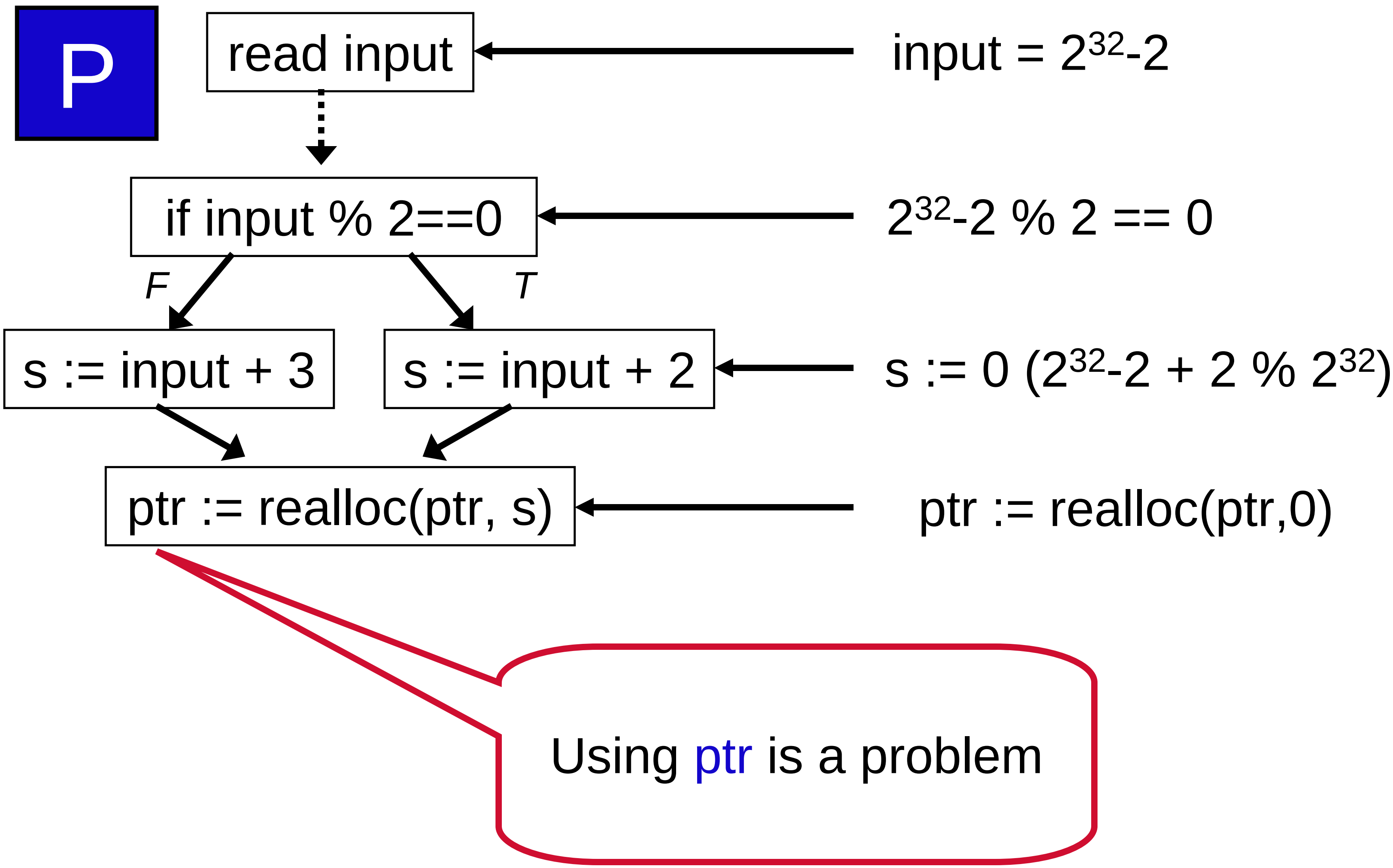
- **Why care?**
  - **Exploits worth money**
    - » **Typically $10,000 - $100,000**
  - **Know thy enemy**
    - » **Security of patch distribution schemes?**
  - **Patch testing**

Running Example



- **All integers unsigned 32-bits**
- **All arithmetic mod 2^{32}**
- **Motivated by real-world vulnerability**

Running Example



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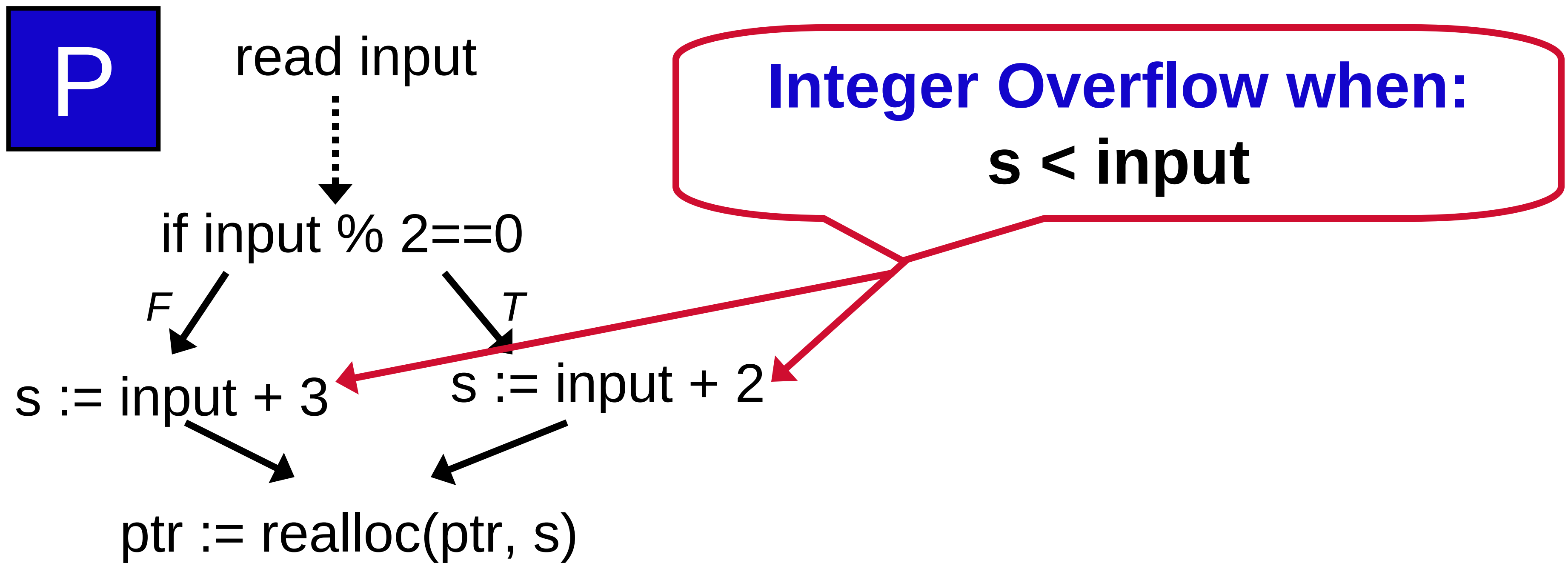

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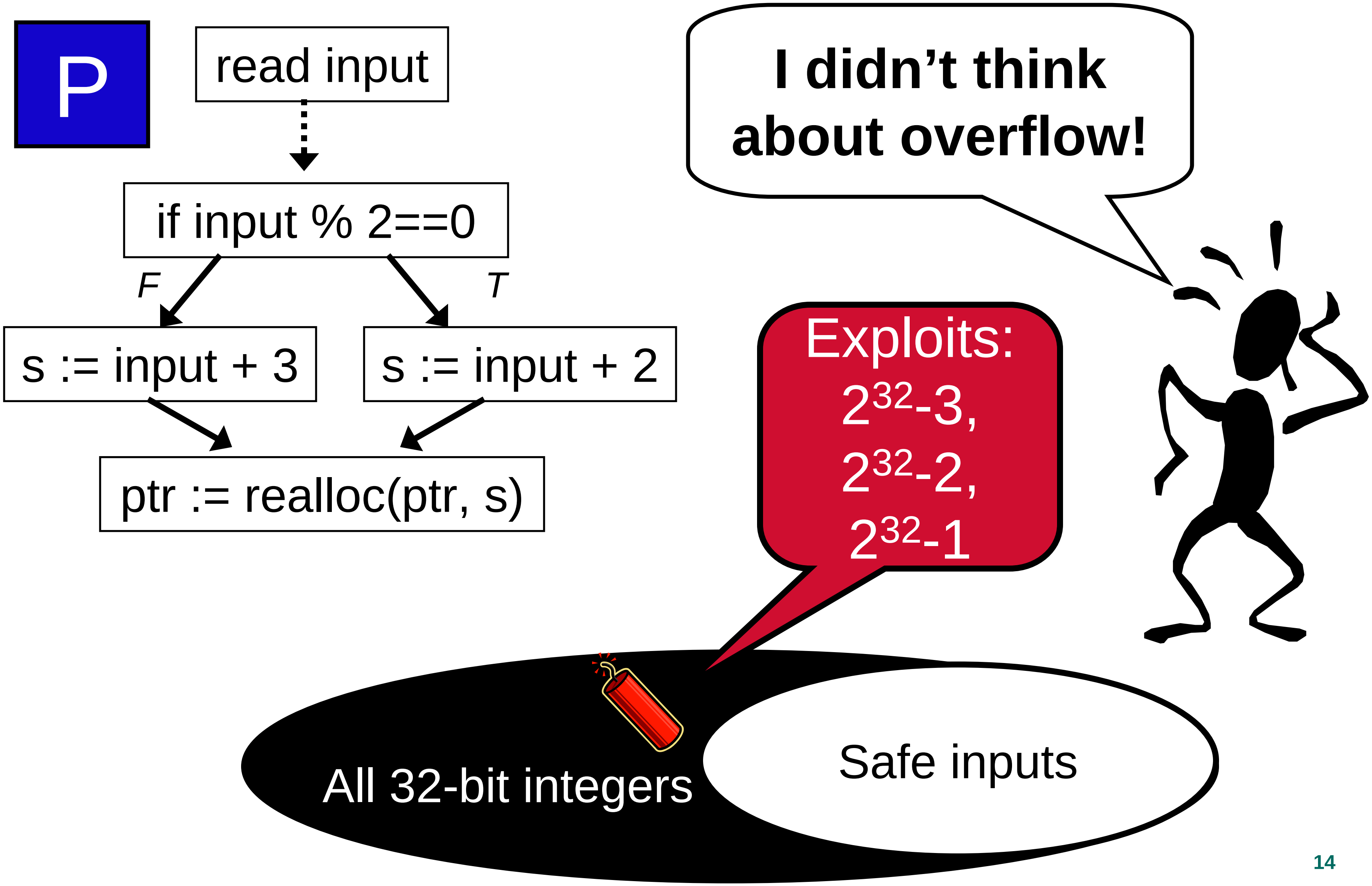
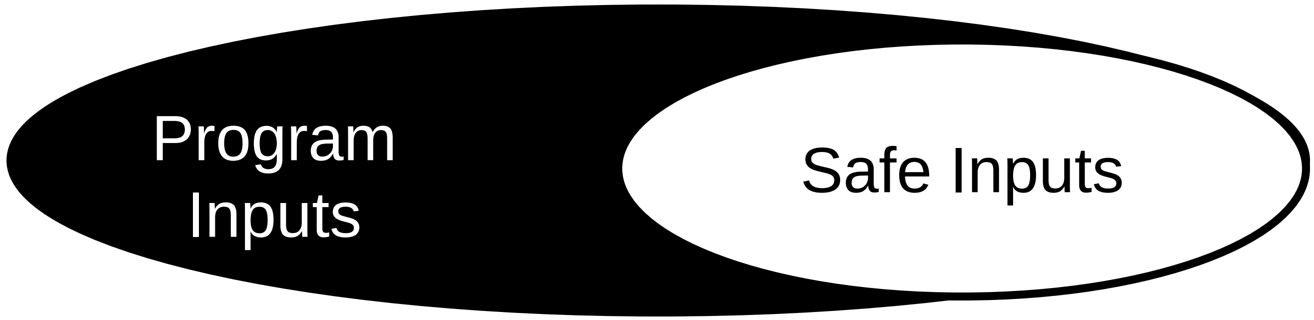
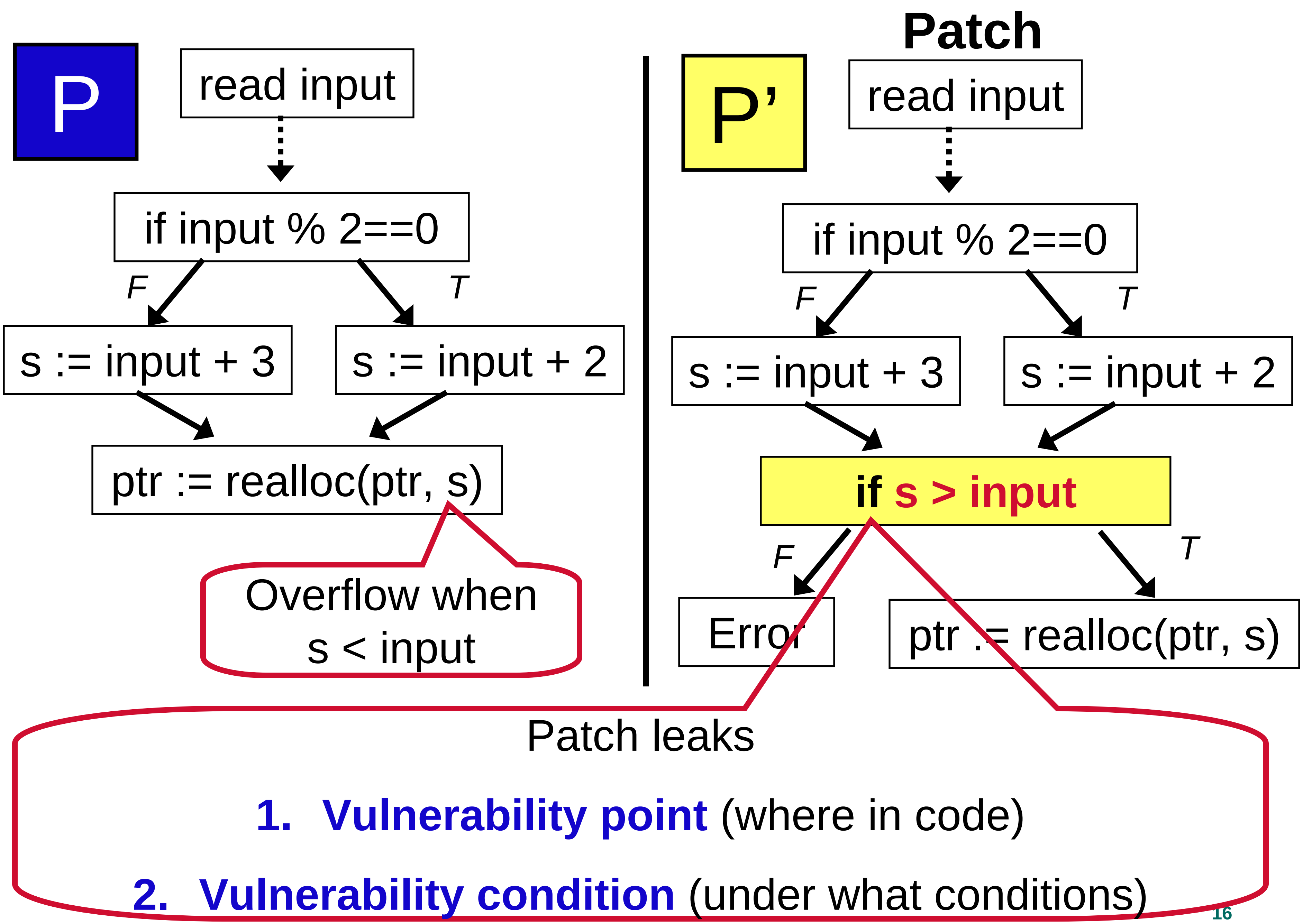


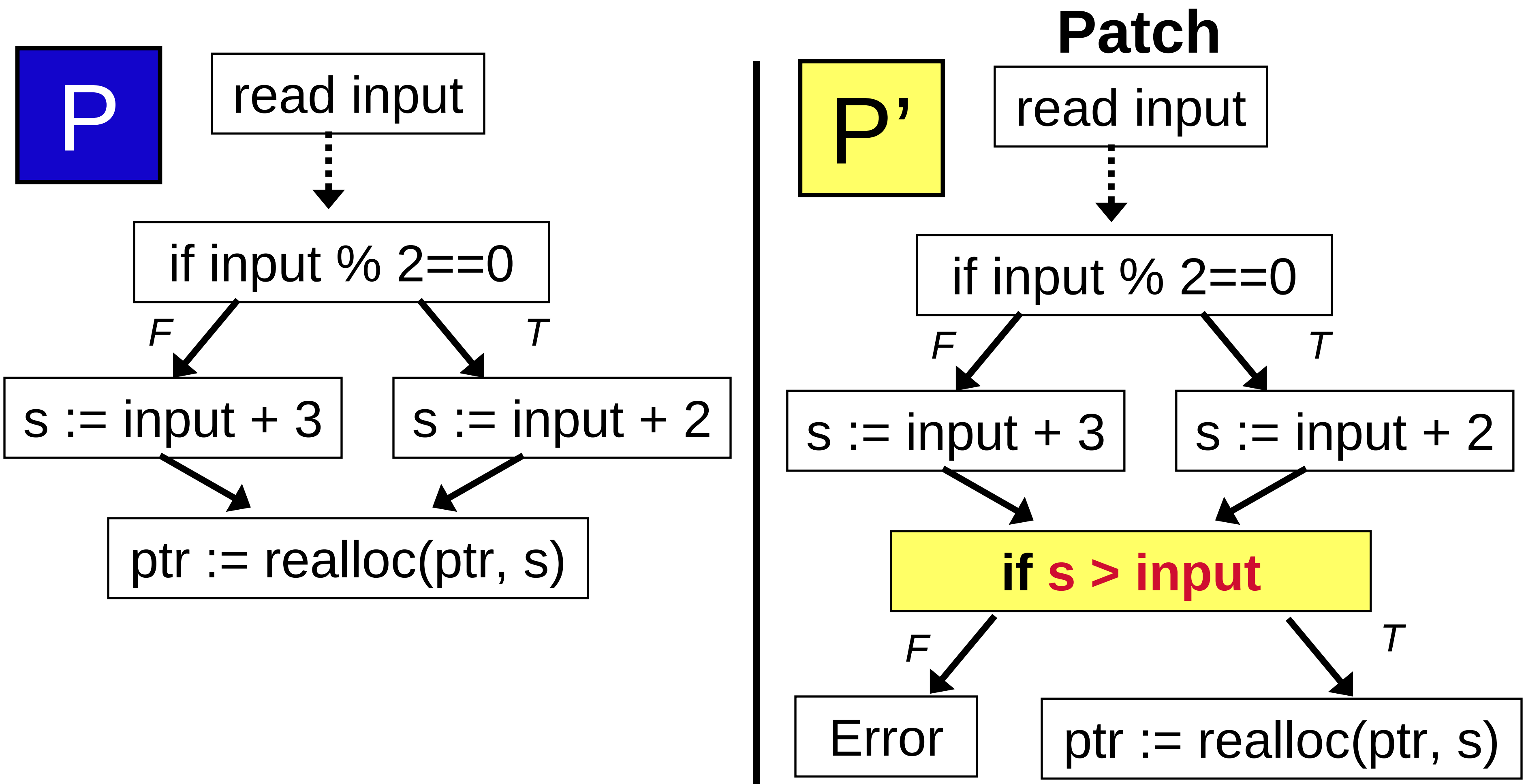


Input Validation Vulnerability

- **Programmer fails to sanitize inputs**
- **Large class of security-critical vulnerabilities**
  - **"Buffer overflow", "integer overflow", "format string vulns", etc.**
- **Responsible for many, many compromised computers**



Patch
P
read input
if input % 2==0
F
T
s := input + 3
s := input + 2
ptr := realloc(ptr, s)
Overflow when
s < input
P'
read input
if input % 2==0
F
T
s := input + 3
s := input + 2
if s > input
F
T
Error
ptr := realloc(ptr, s)
Patch leaks
1. Vulnerability point (where in code)
2. Vulnerability condition (under what conditions)



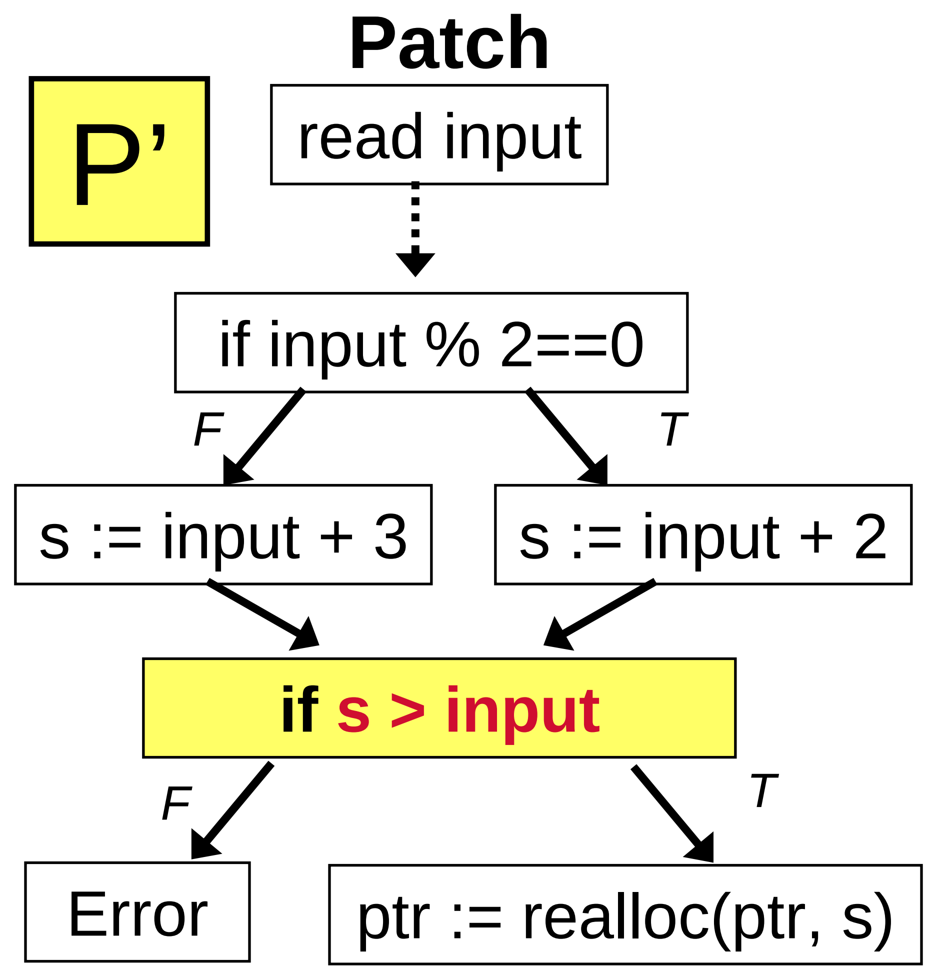
Exploits for P are inputs that fail vulnerability condition at vulnerability point

(s > input) = false

Our Approach for Patch-based Exploit Generation (I)

Exploit Generation

1. **Diff P and P' to identify candidate vuln point and condition**
2. **Create input that satisfy candidate vuln condition in P'**
   - **i.e., candidate exploits**
3. **Check candidate exploits on P**



Our Approach for Patch-based Exploit Generation (II)

- **Diff P and P' to identify candidate vuln point and condition**
  - **Currently only consider inserted sanity checks**
  - **Use binary diffing tools to identify inserted checks**
    - » **Existing off-the-shelf syntactic diffing tools**
    - » **BinHunt: our semantic diffing tool**
- **Create candidate exploits**
  - **i.e., input that satisfy candidate vuln condition in P'**
- **Validate candidate exploits on P**
  - **E.g., dynamic taint analysis (TaintCheck)**

Create Candidate Exploits

- **Given candidate vulnerability point & condition**
- **Compute Weakest Precondition over program paths**
  - **Using vulnerability condition as post condition**
  - **Construct formulas representing conditions on input**
    - **Whose execution path included**
    - **Satisfying the vulnerability condition at vulnerability point**
- **Solve formula using solvers**
  - **E.g., decision procedures**
  - **Satisfying answers are candidate exploits**

Different Approaches for Creating Formulas

- **Statically computing formula**
  - **Covering many paths (without explicitly enumerating them)**
  - **Sometimes hard to solve formula**
- **Dynamically computing formula**
  - **Formula easier to solve**
  - **Covering only one path**
- **Combined dynamic and static approach**
  - **Covering multiple paths**
  - **Tune for formula complexity**
- **Experimental results**
  - **Different approach effective for different scenarios**
- **Other techniques to make formulas smaller and easier to solve**

Experimental Results

- **5 Microsoft patches**
  - **Mostly 2007**
  - **Integer overflow, buffer overflow, information disclosure, DoS**
- **Automatically generated exploits for all 5 patches**
  - **In seconds to minutes**
  - **3 out of 5 have no publicly available exploits**
  - **Automatically generated exploit variants for the other 2**
- **Diffing time**
  - **A few minutes**

Exploit Generation Results

Time (s)	DSA_SetItem	ASPNet _Filter	GDI	IGMP	PNG
Dynamic Total	5.68	11.57	10.34	N/A	N/A
Formula	5.51	4.64	10.33	N/A	N/A
Solver	0.17	6.93	0.01	N/A	N/A
Static Total	83.47	N/A	26.41	N/A	N/A
Formula	2.32	N/A	4.99	N/A	N/A
Solver	81.15	N/A	21.42	N/A	N/A
Combined	11.51	N/A	29.07	13.57	104.28
Forumla	6.72	N/A	25.29	13.31	104.14
Solver	4.79	N/A	3.78	0.26	0.14

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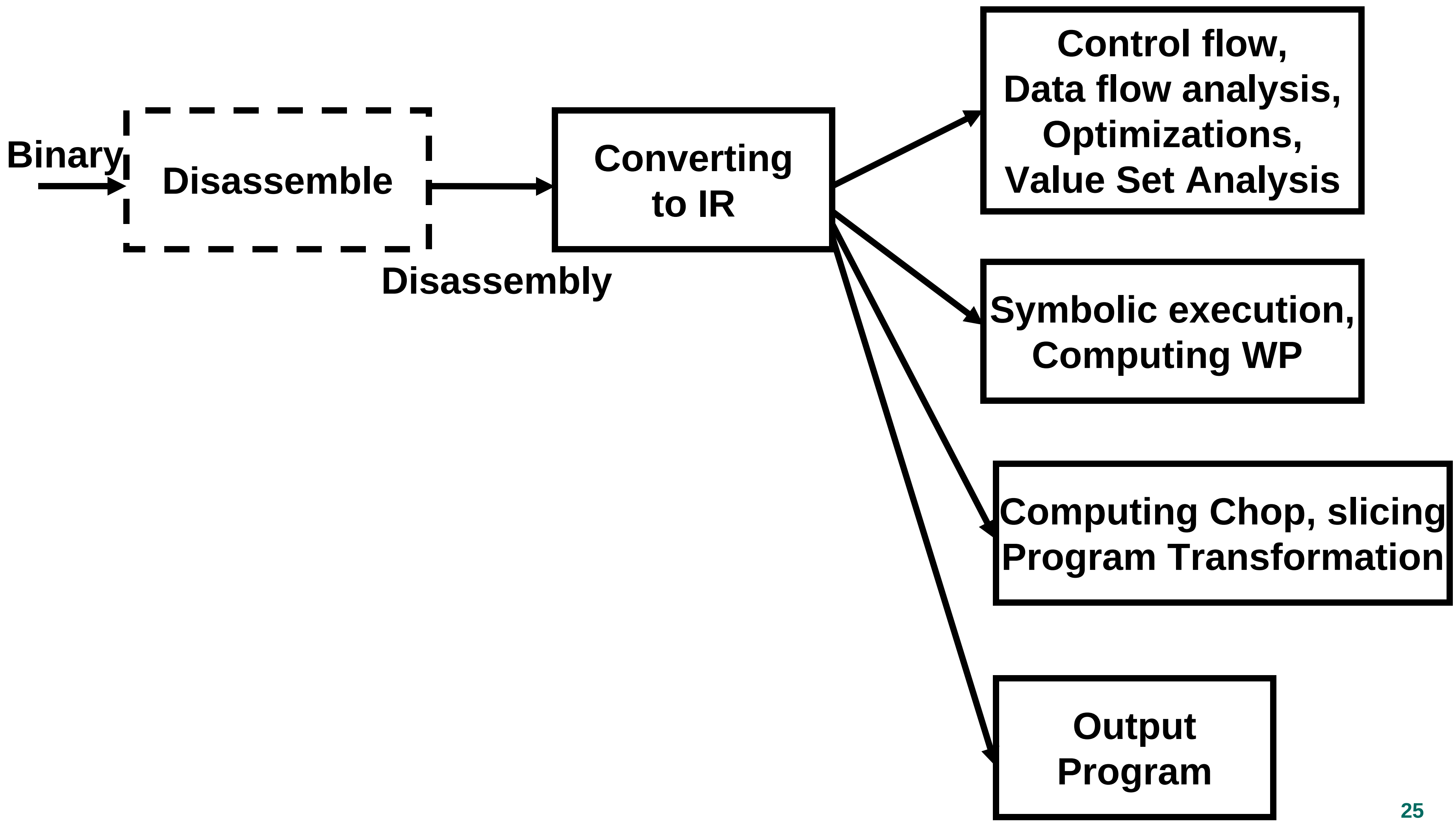
Vine

- **Static analysis component**



Vine IR

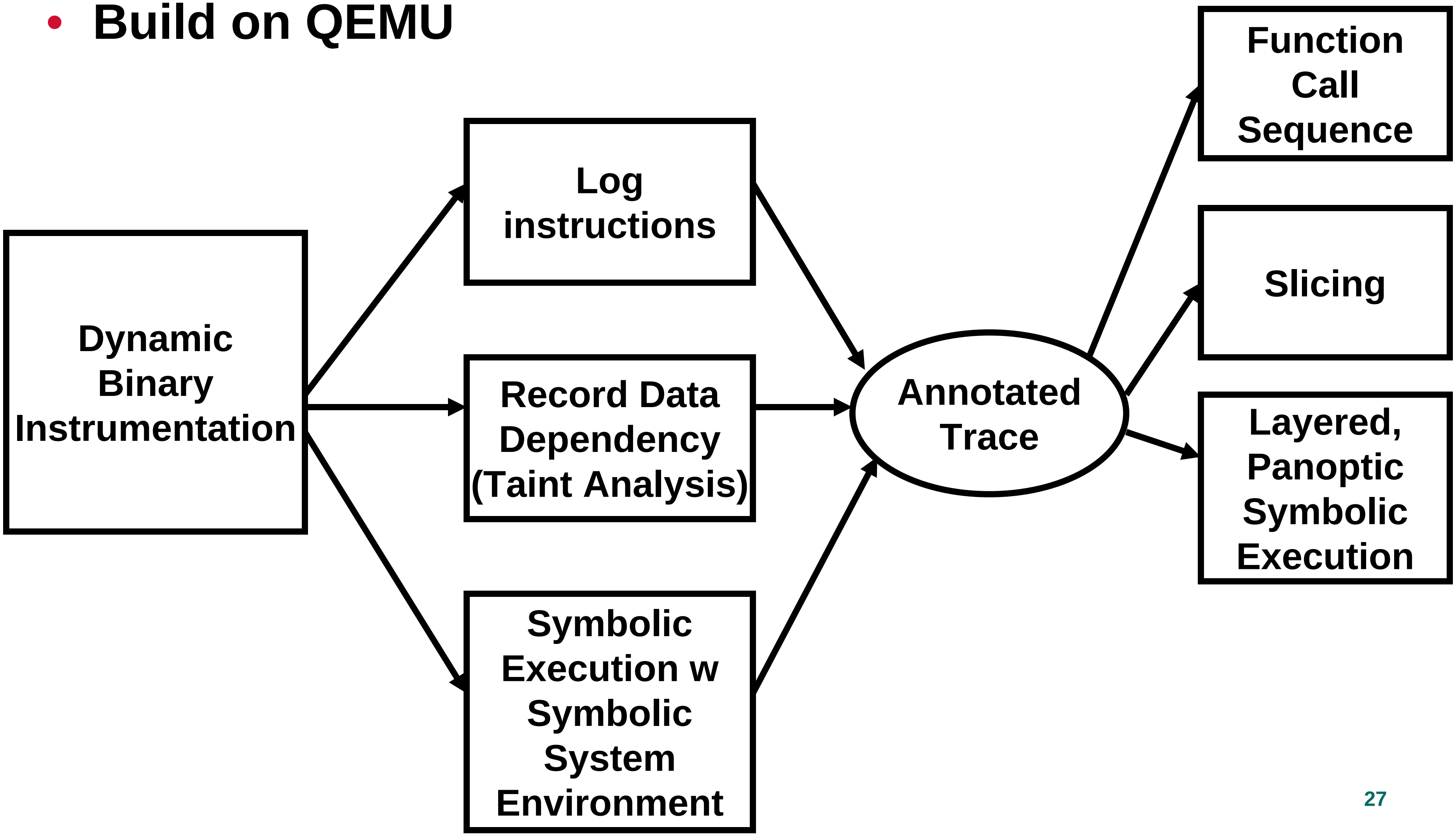
- **Simple RISC-like language, well-typed**

```
  lval := exp
| goto exp
| if exp then goto exp1 else exp2
| return exp
| call exp
| assert exp
| special exp
| unknown (effects)
```

- **Handle x86, and ARM in progress**

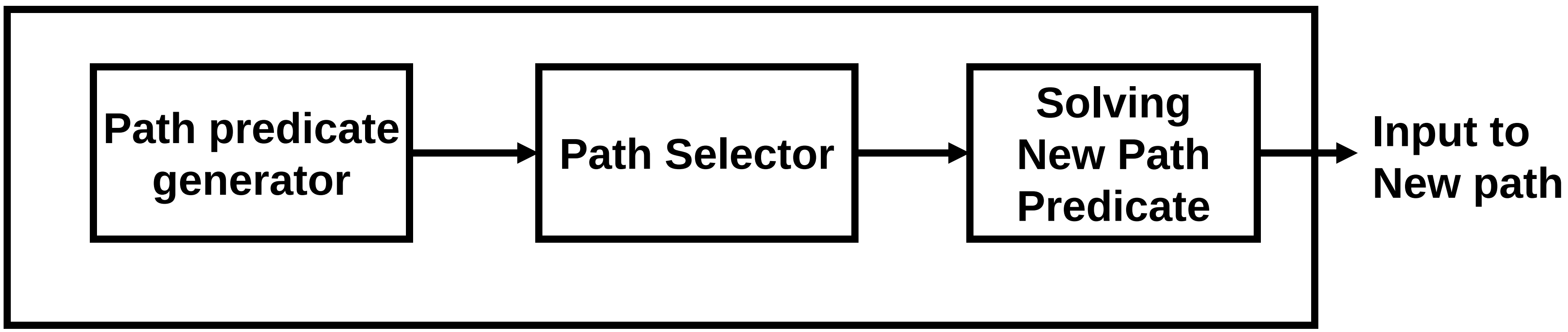
TEMU

- Work for both Windows & Linux, applications & kernel
- Build on QEMU



Rudder

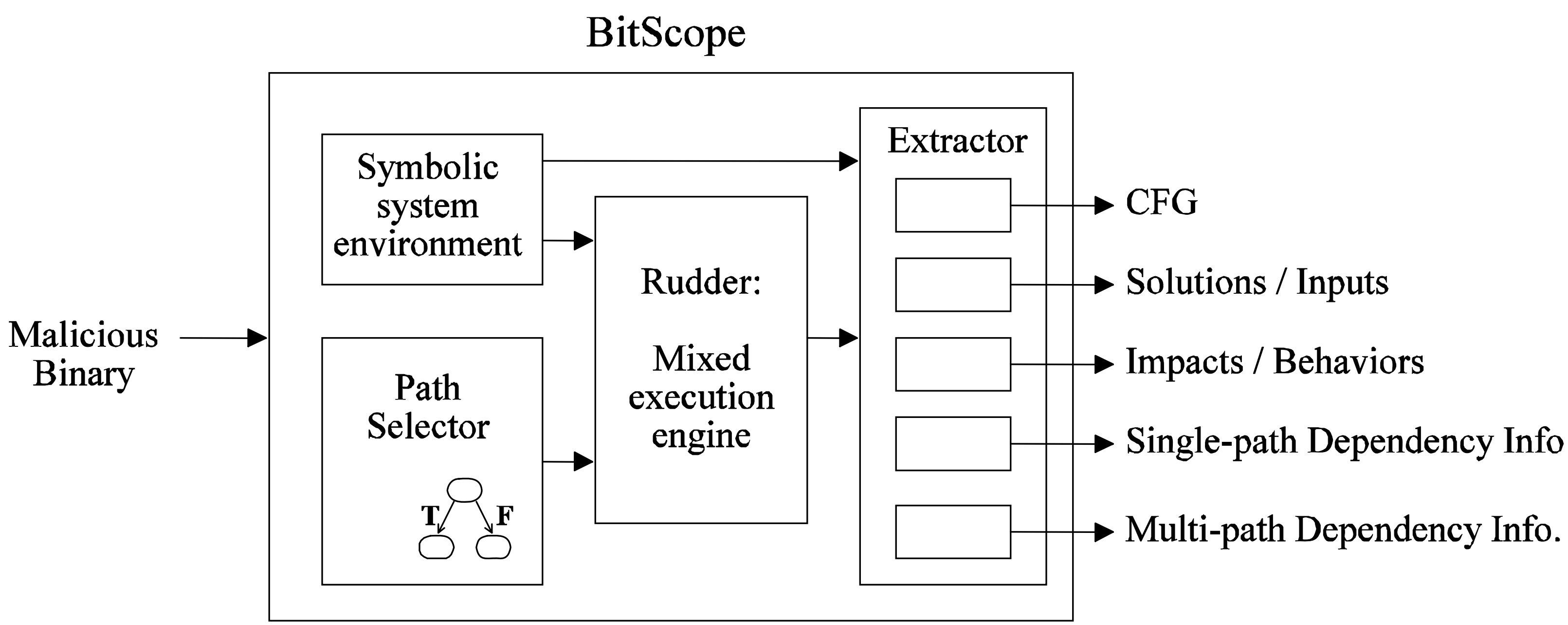
- Compute path predicate
- Obtain new path predicate by reverting branches
- Solve path predicate to obtain new input to go down a different path



Rudder

BitScope

- **Built on top of TEMU & Rudder**
- **Work for packed code, self-encrypted code**



BitScope: THE In-depth Malware Analysis infrastructure

- **Identify/analyze malicious behavior based on root cause**
  - **Privacy-breaching malware: spyware, keylogger, backdoor, etc.**
  - **Malware perturbing system by hooking: rootkit, etc.**
- **Understand how malware get into the system**
  - **What mechanisms/vulnerabilities does it exploit**
- **Explore hidden behavior, detect trigger-based behavior**
  - **Automatically identifying botnet program commands, time bombs, etc.**
- **Semantic & correlation analysis of malware input/output behavior**
  - **Understanding the semantics of botnet program commands, etc.**

Challenges

- **Performance & scalability for large programs**

- **Sample components we can take advantage of**
  - **Better identification of functions & resolution of indirect jumps**
    - **Some of our VSA techniques may help**
  - **Better stack-walker**
  - **Binary aliasing analysis**
  - **More efficient binary instrumentation**

Conclusion

- **BitBlaze binary analysis platform**
  - **A unique fusion of dynamic, static analysis & formal analysis (symbolic execution, WP, etc.)**
- **Security Applications**
  - **Vulnerability discovery, diagnosis, defense**
  - **In-depth malware analysis**
  - **Reverse engineering**
  - **Binary diffs**
- **Components may support other applications**

Contact

- http://bitblaze.cs.berkeley.edu

- dawnsong@cs.berkeley.edu

- **BitBlaze team:**
  David Brumley, Juan Caballero, Ivan Jager, Cody Hartwig, Min Gyung Kang, Zhenkai Liang, James Newsome, Pongsin Poosankam, Prateek Saxena, Heng Yin