Dowsing for overflows: a guided fuzzer to find buffer boundary violations

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Bugs, bugs everywhere

- Buffer overflows still represent a top 3 threat (after 40 years)
- Applications grow at a rapid pace, testing cannot keep up
- Containment of software faults?
- Solve the root cause via automated testing!

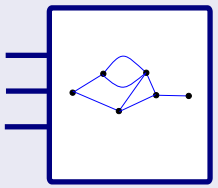
Possibility of automated testing

Static analysis

- Deployed in practice
- Difficult to make path-sensitive and inter-procedural
- Lack of accuracy makes for many FPs/FNs

Symbolic execution

- Observations only relevant for given execution path
- Core focus is on input generation
- Goal is to achieve significant code coverage
- Exponential in nature (input/code)



Testing model

- Search for buffer overflows
  - Dowser focuses on complex loops
  - Other approaches for simple pointer computation
- Source code available: Typical in testing
- Existing test inputs to reach every complex loop

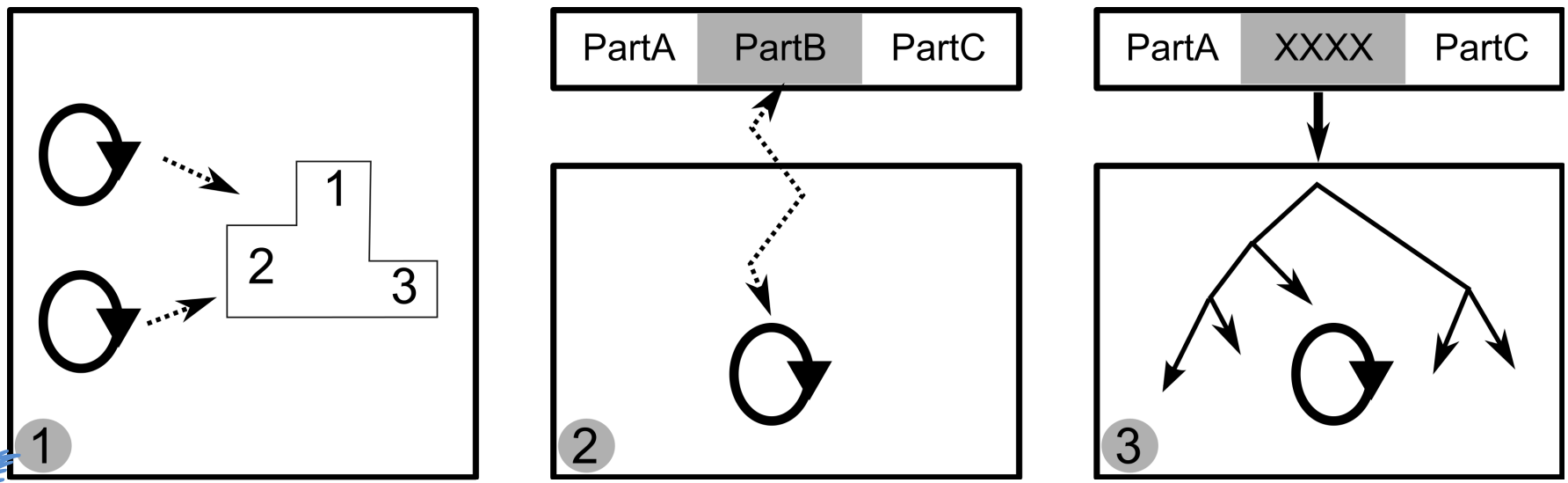
Example

- Nginx web server, buffer overflow in URI parser
- Application too complex for traditional tools
- Complete code coverage may not even the trigger bug!

```
while (p <= r->uri_end) // >300 lines of code
    switch (state)
    case sw_usual: *u++ = ch; ...
    case sw_slash: *u++ = ch; ...
    ...
    case sw_dot: *u++ = ch; ...
        if (ch == '/') u--; ...
    case sw_dot_dot: *u++ = ch; ...
        if (ch == '/') u -= 4; ...
    ...
```

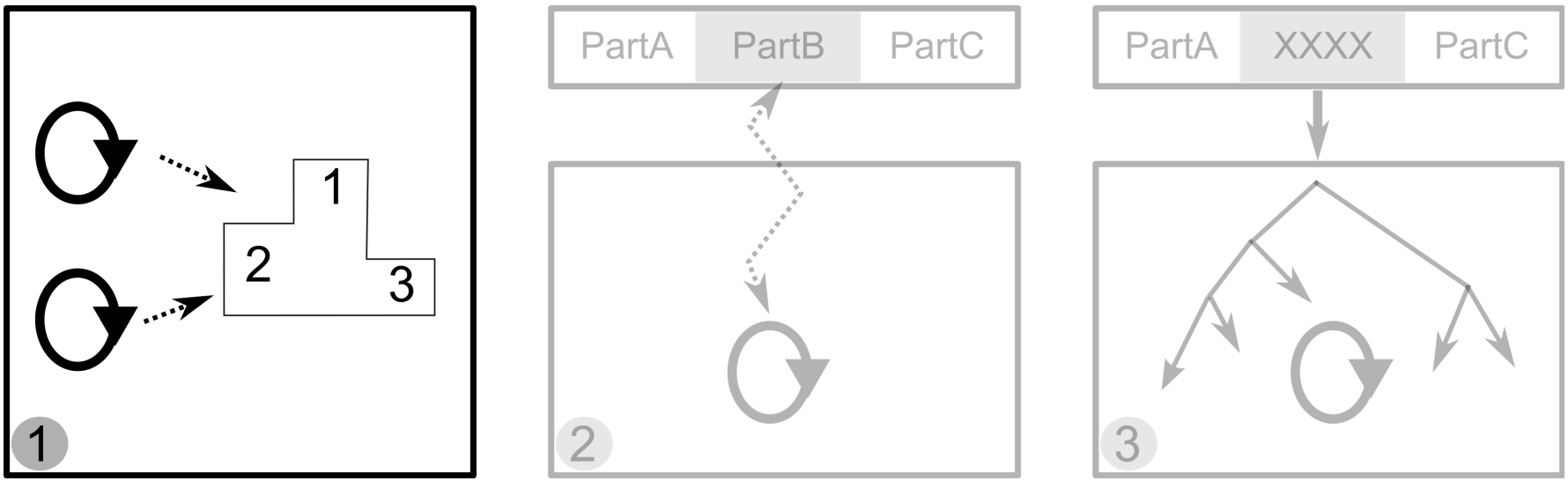
Testing with Dowser

- **Objective**: focus the testing effort around specific high-priority code fragments
- **Spot-checking** instead of looking at general picture
- Builds on symbolic execution, guided by in-depth analysis
- End-to-end solution starting from source-code:



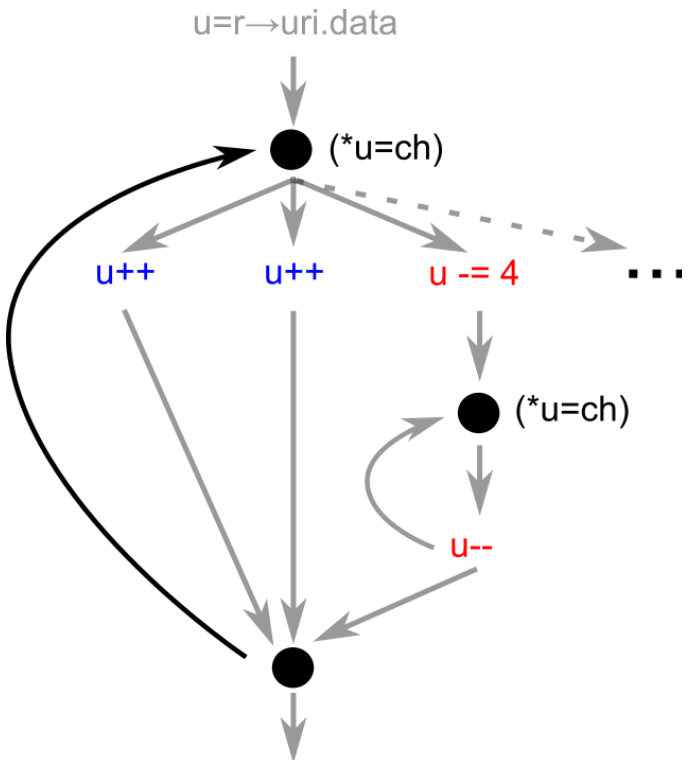
Dowsing

Identify and rank loops based on bug probability



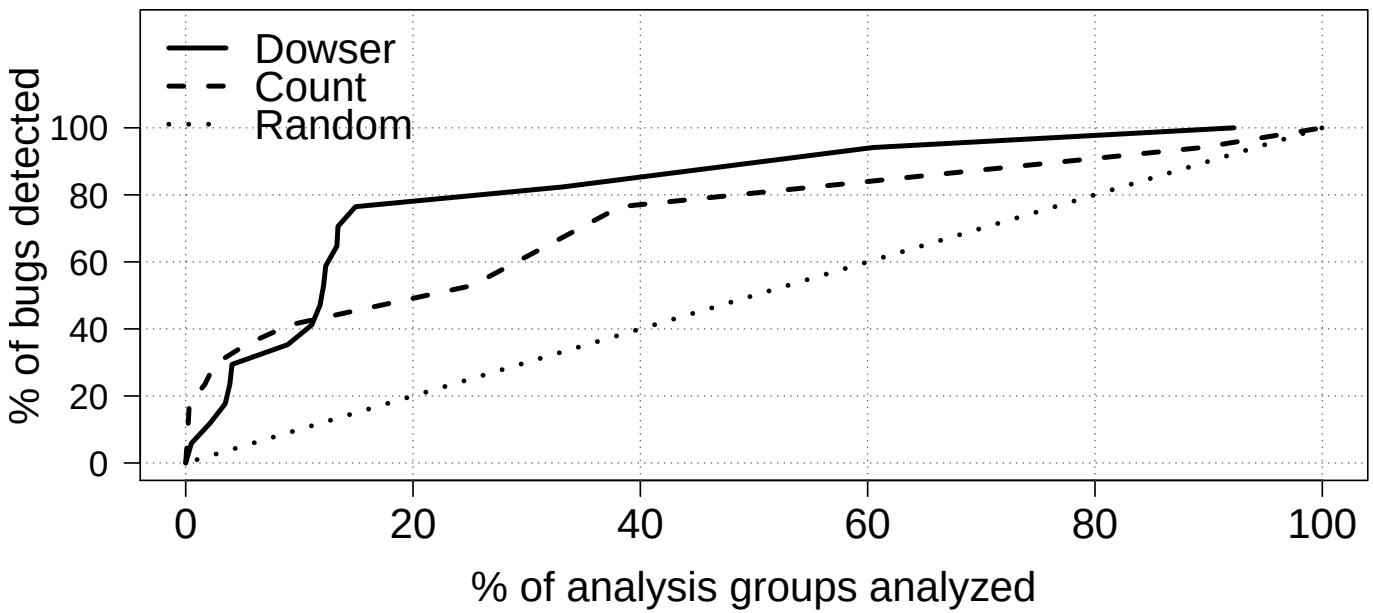
Dowsing in a nutshell

- Static analysis during compilation process
- Search for loops containing pointer dereference
- Analyze data-flow graph to infer complexity measure



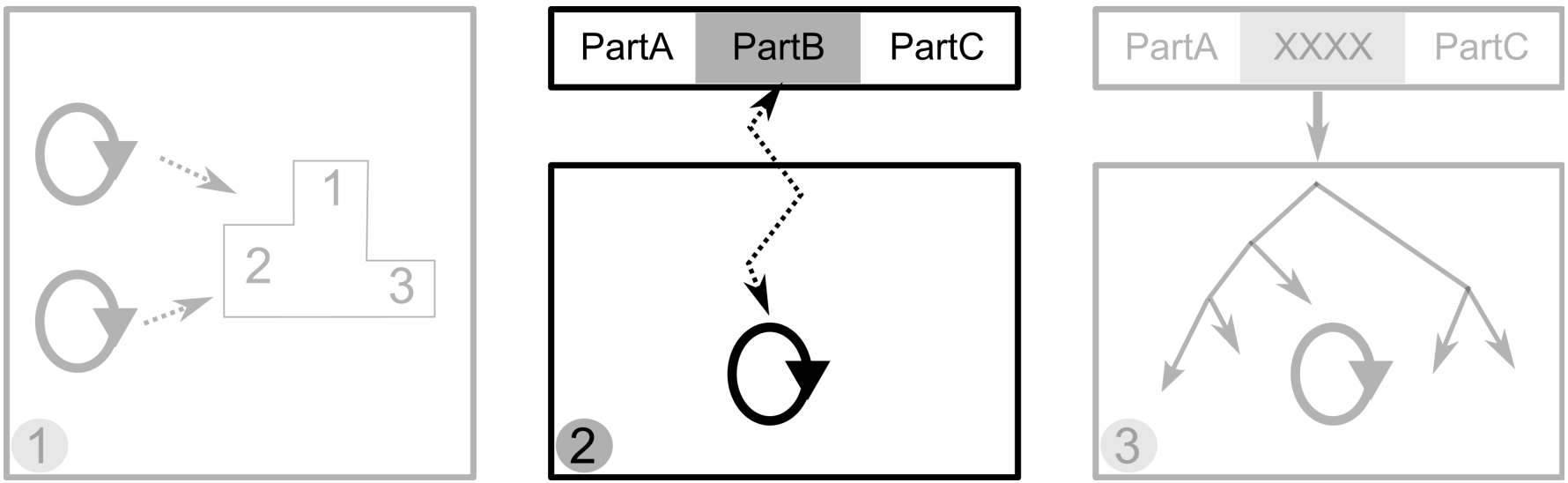
Applied to real software

- Compare the ranking efficiency of the proposed heuristic to instruction counting and random order
- Buffer overflows reported in CVE for: `nginx`, `ffmpeg`, `inspircd`, `libexif`, `poppler`, `snort`, `sendmail`



Input tracking

Only sub-set of input is relevant for spot-checking
Infer relationships between inputs and candidate loops



Example input: HTTP Request

Long input with multiple tokens.

GET /long/path/file HTTP/1.1
Host: thisisthehost.com
Content-Type: application/x-www-form-urlencoded
Content-Length: 1337

Highlight of HTTP Request

Only small part influences given loop

```
GET /long/path/file HTTP/1.1
Host: thisisthehost.com
Content-Type: application/x-www-form-urlencoded
Content-Length: 1337
```

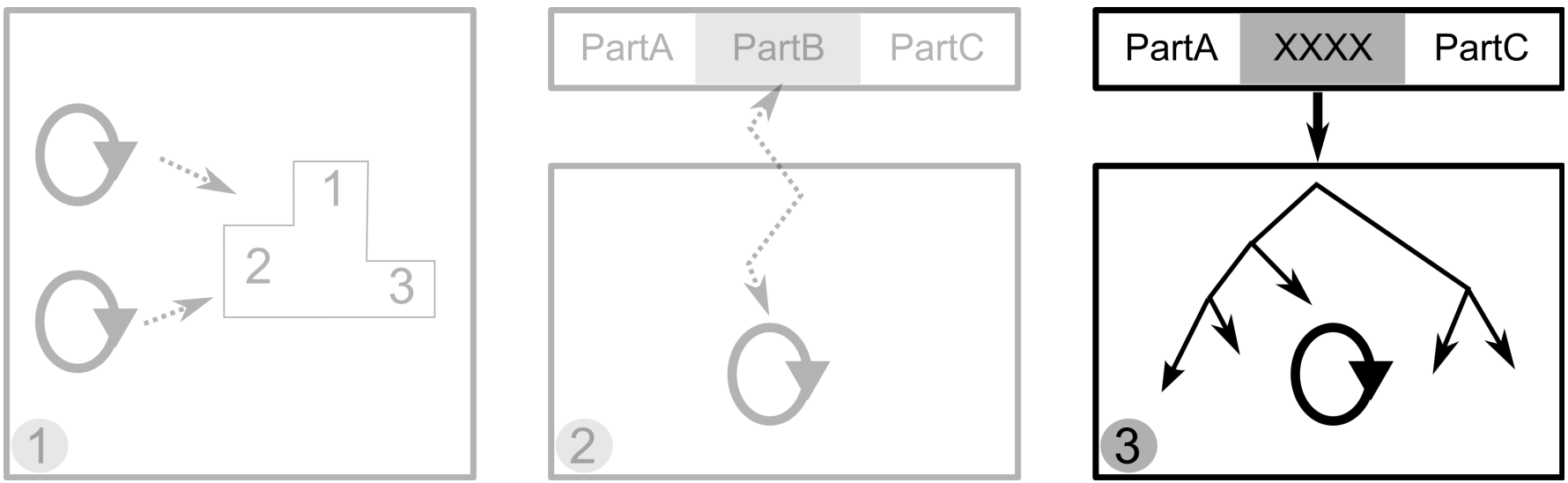
- Dynamic information flow tracking
- Track the influence of input on variables
- Can be performed at different granularities (details in paper)

Benefits of input reduction

- Symbolic execution is input driven in nature
- Provides implicit fine-grained modularization
- Enables symbolic execution for applications with large input
  - Conversion table in movie file for `ffmpeg`
  - Font description in PDF file for `poppler`

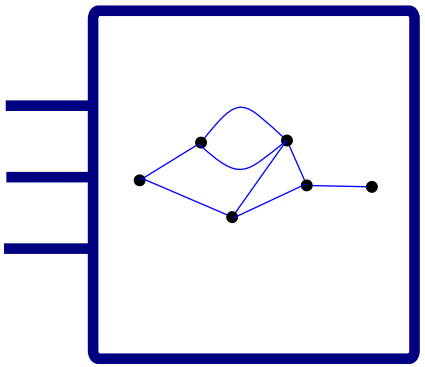
Bug search

Guide symbolic execution towards potential bug



Basics of symbolic execution

- "White-box fuzzing"
- Avoid generating input that replicates execution path
- Run-time feed-back about possible execution paths
- Aimed at test-case generation

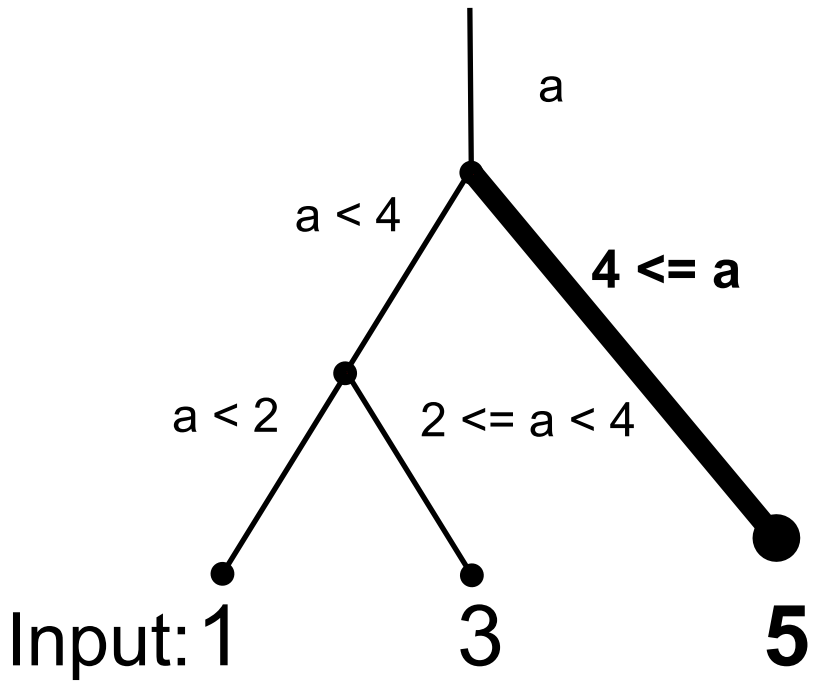


Snippet of symbolic execution

Constraint solver used to check for possible divergence

```
if (a < 4)
  do_something1;
else
  do_something2;

if (a < 2)
  do_something3;
else
  do_something4;
```



Analyzing symbolic execution

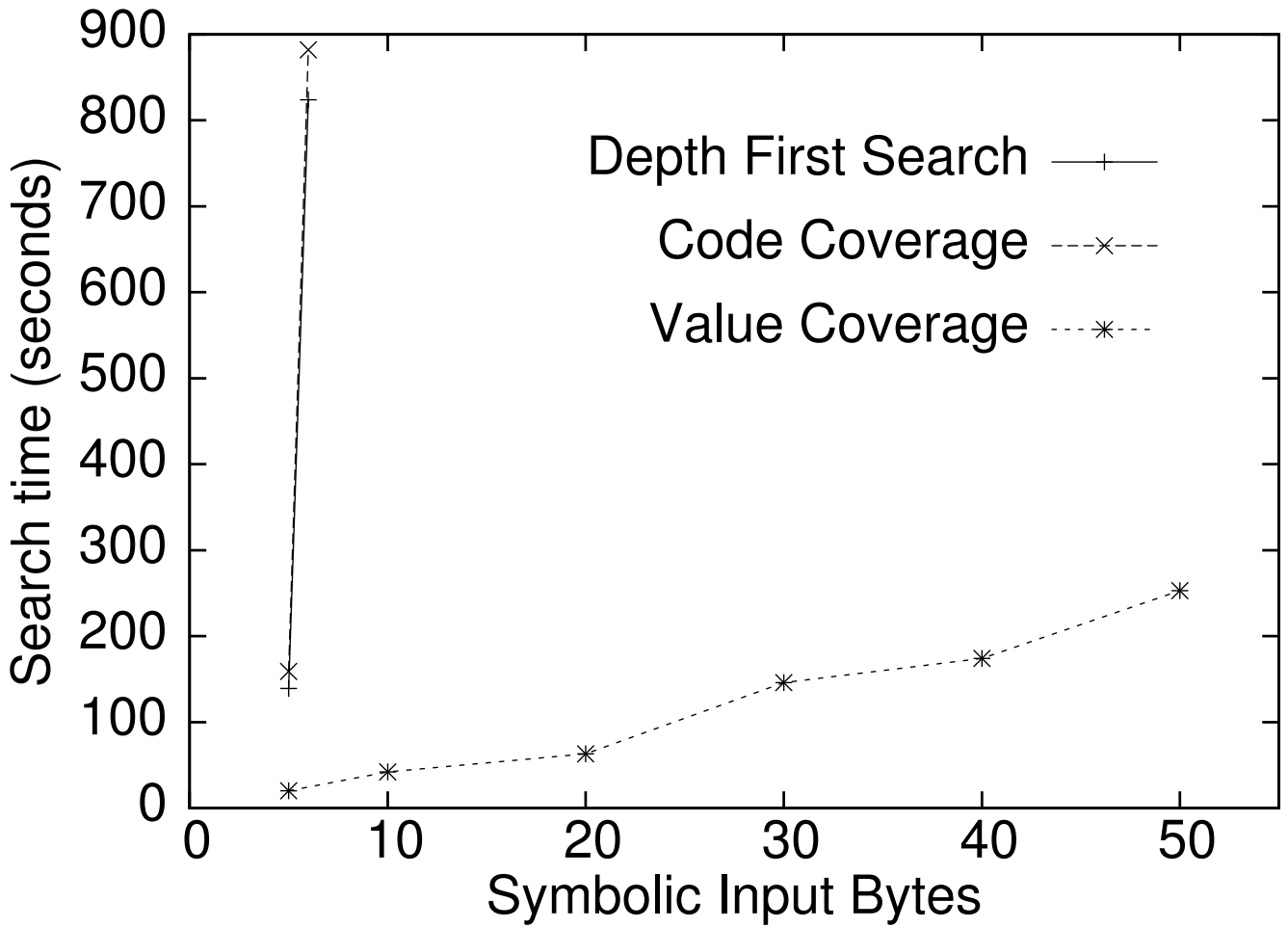
- In practice input reduction was found to be insufficient
- Large number of conditional branches still to be covered

Only some conditional statements are relevant

```
if (a[i] == 'A')
  printf(...);
```

- Focus on the branches influencing pointer value
- **Value Coverage** search strategy

Value Coverage vs traditional search strategies



Details behind Value Coverage Search

- Only some execution paths are relevant to pointer arithmetic
- Learn the general behavior of conditionals using small inputs
- Result: 66% of conditionals eliminated
- Influence on example:

```
while (p <= r->uri_end)
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                        u--;
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                        u -= 4;
```

Evaluation

Program	LoC	Symbolic Input	Symbolic execution		
			Symbex	M-Symbex	Dowser
nginx 0.6.32	66k	URI field	$>$ 8 h	$>$ 8 h	253 sec
ffmpeg 0.5	300k	Huffman table	$>$ 8 h	$>$ 8 h	48 sec
inspircd 1.1.22	45k	DNS response	200 sec	200 sec	32 sec
poppler 0.15.0	120k	JPEG image	$>$ 8 h	$>$ 8 h	14 sec
poppler 0.15.0	120k	Embedded font	$>$ 8 h	$>$ 8 h	762 sec
libexif 0.6.20	10k	EXIF tag/length	$>$ 8 h	652 sec	652 sec
libexif 0.6.20	10k	EXIF tag/length	$>$ 8 h	347 sec	347 sec
libexif 0.6.20	10k	EXIF tag/length	$>$ 8 h	277 sec	277 sec
snort 2.4.0	75k	UDP packet	$>$ 8 h	$>$ 8 h	617 sec

Table: Bugs detected with Dowser.

Conclusions

- End-to-end solution for guided symbolic execution
- The spot-check approach enables focused search
- Built-in prioritization mechanism to optimize testing effort
- Heuristics geared towards buffer overflow type bugs
- Dowser shows scalability beyond traditional tools