HASE

Hardware-Assisted Symbolic Execution

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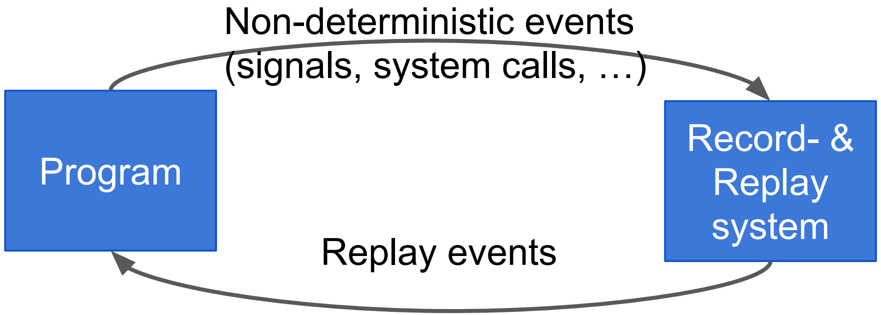
Motivation

- Reproducing bugs that occur in production is hard
  - To fix bugs, developers have to reproduce them to understand the root cause
- Developers currently rely on
  - Stack traces
  - OS environment information
  - Coredumps
  - User reports

How can we make it easier to reproduce bugs?

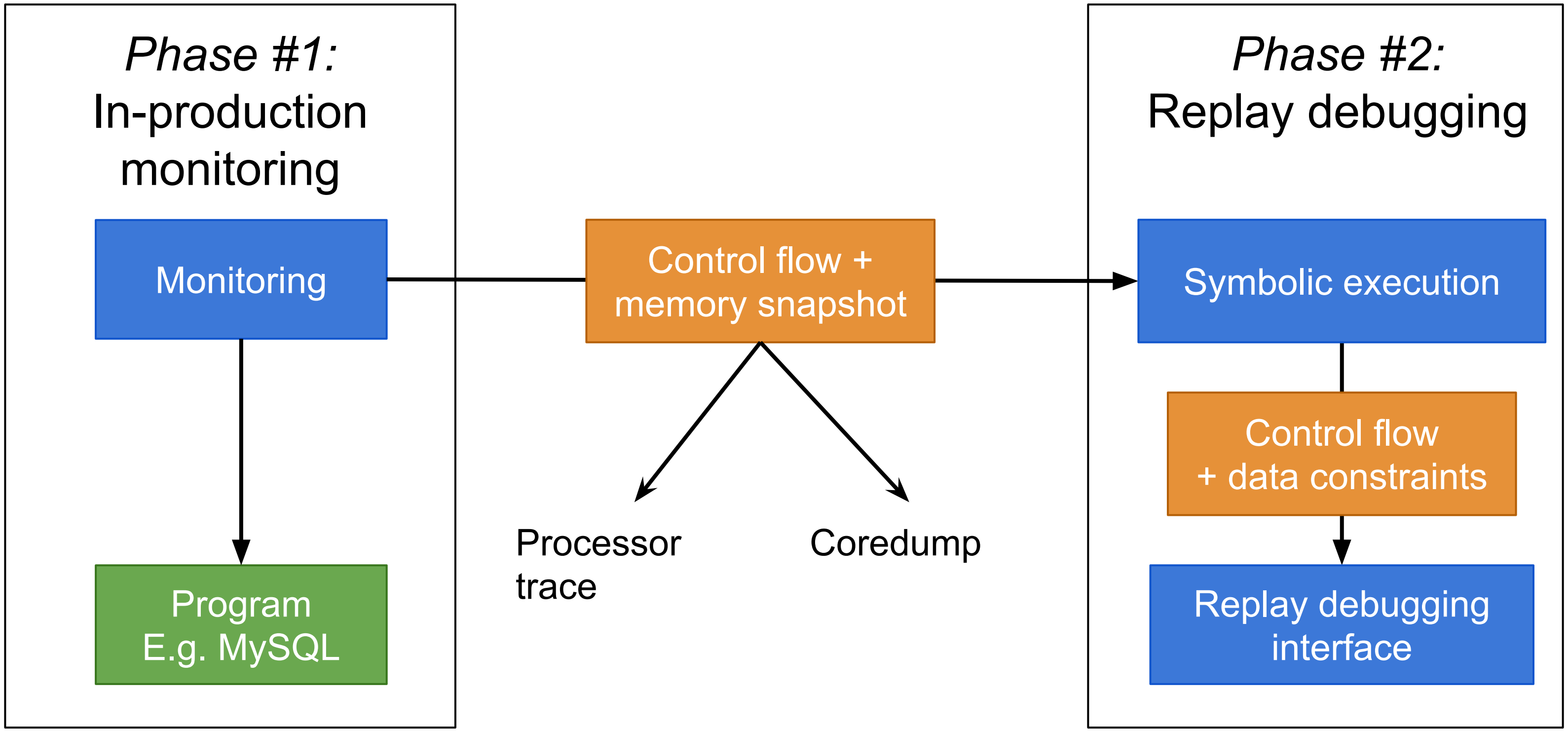
State-of-the-art: Replay debugging



- Limitation: High overheads for production
  - RR [Mozilla]: 1.2x - 1.4x
  - ODR [SOSP’09]: 1.6x - 3.5x
  - DoublePlay [ASPLOS’11]: 1.15x - 1.28x

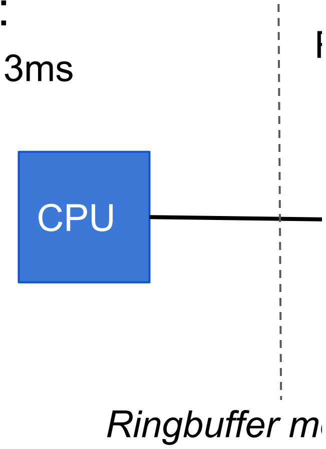
How can we reduce the overhead to allow continuous logging?

System design



Background: Intel Processor Trace (PT)

- Since Broadwell generation (2014)
- Records full instruction history with **low** overhead (3%)*
- Major limitation: **High log bandwidth** (200MB/s - 2GB/s)
- *Ringbuffer mode* - only keep last X instructions
- E.g. Firefox playing a YouTube video:
  - 5MB trace buffer ~ 192.000 branches ~ 3.3ms

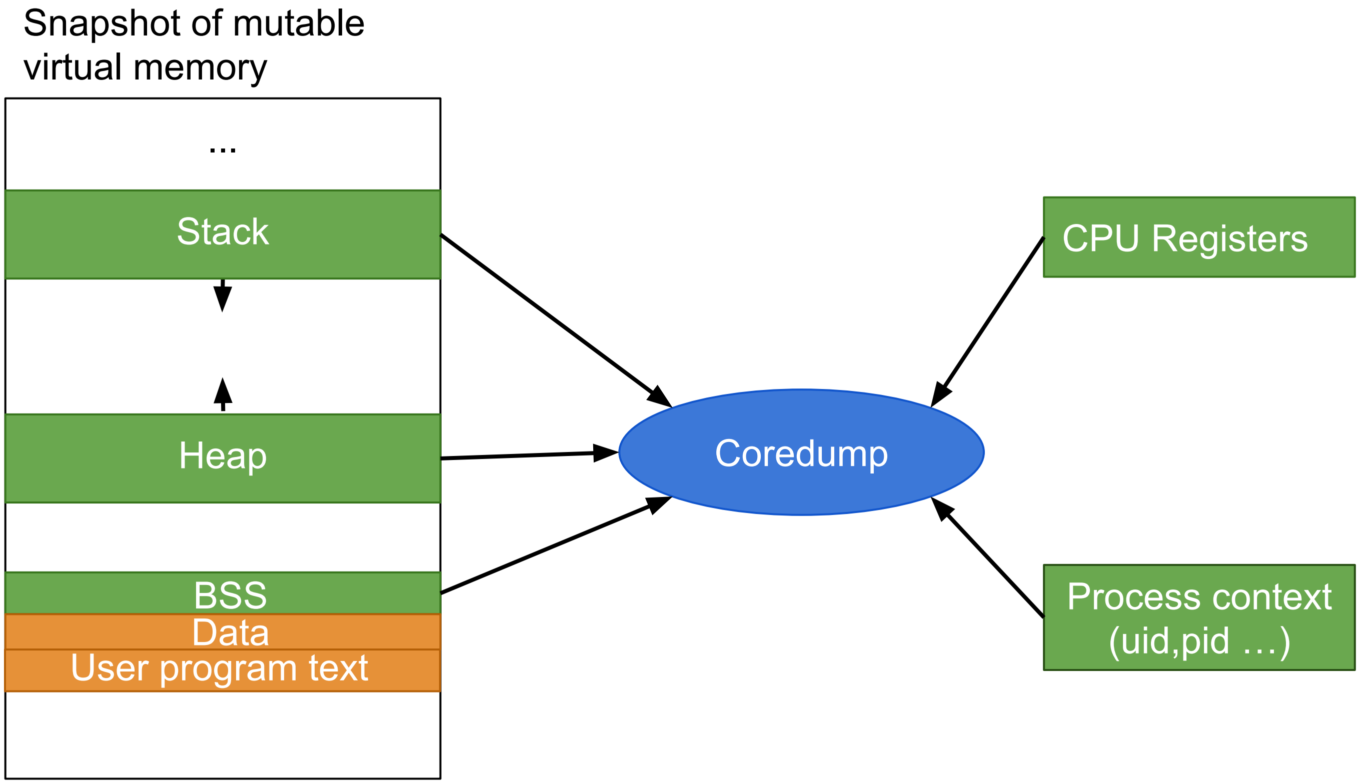


*FlowGuard [HPCA’17]

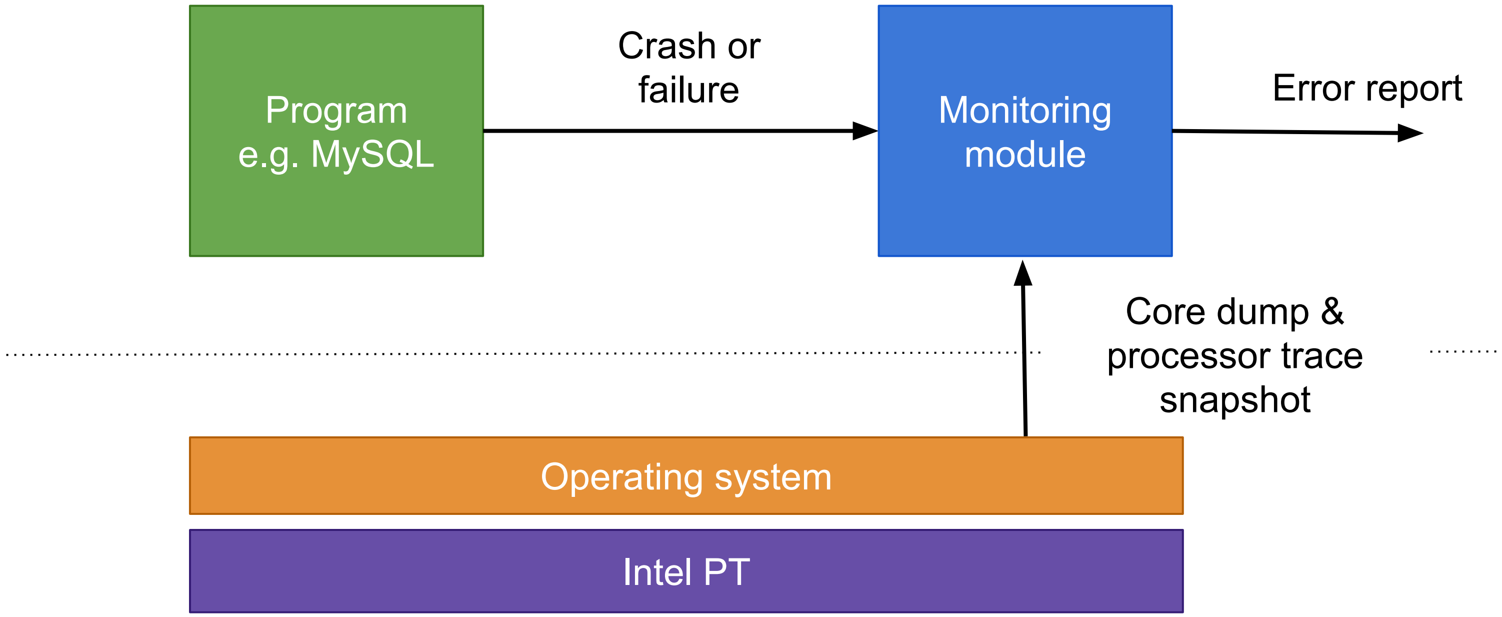
Background: Intel Processor Trace (PT) - bonus

- More information: Andi Kleen’s Blog: http://halobates.de/blog/p/410
- 1 bit per conditional jump
- (optional) time stamps
- Address filtering
- Full system trace possible
- Easy to use:
  - `$ perf record -e intel_pt// program`
- Use cases:
  - Reconstruct every instruction (not just sampling)
  - Very accurate profiling
  - Code coverage (for fuzzing)

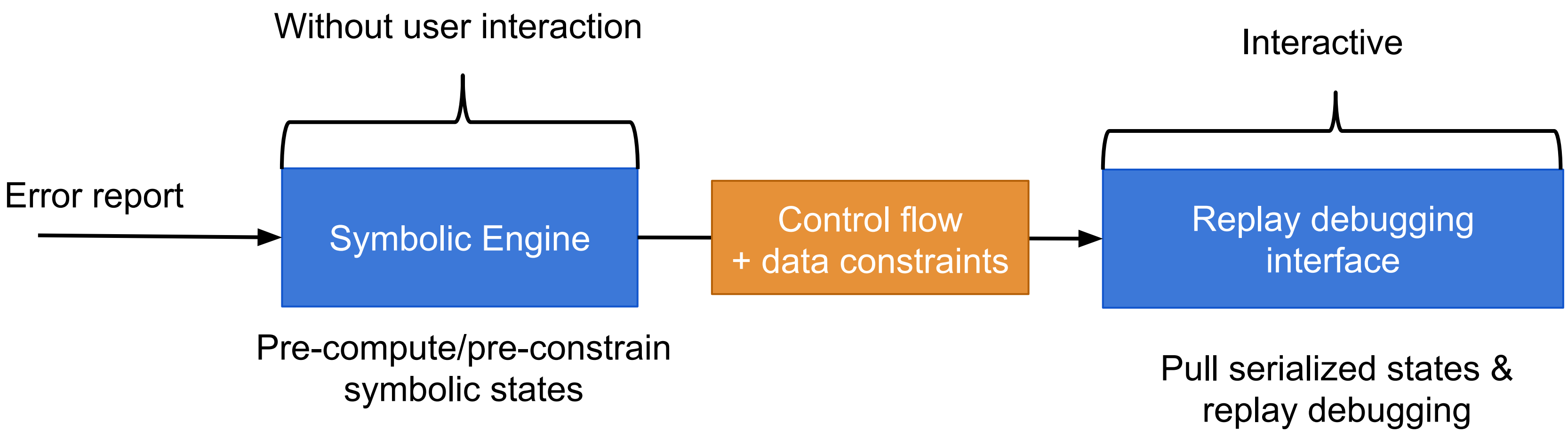
Background: Coredump


Snapshot of mutable virtual memory
...
Stack
Heap
BSS
Data
User program text
Coredump
CPU Registers
Process context (uid,pid …)

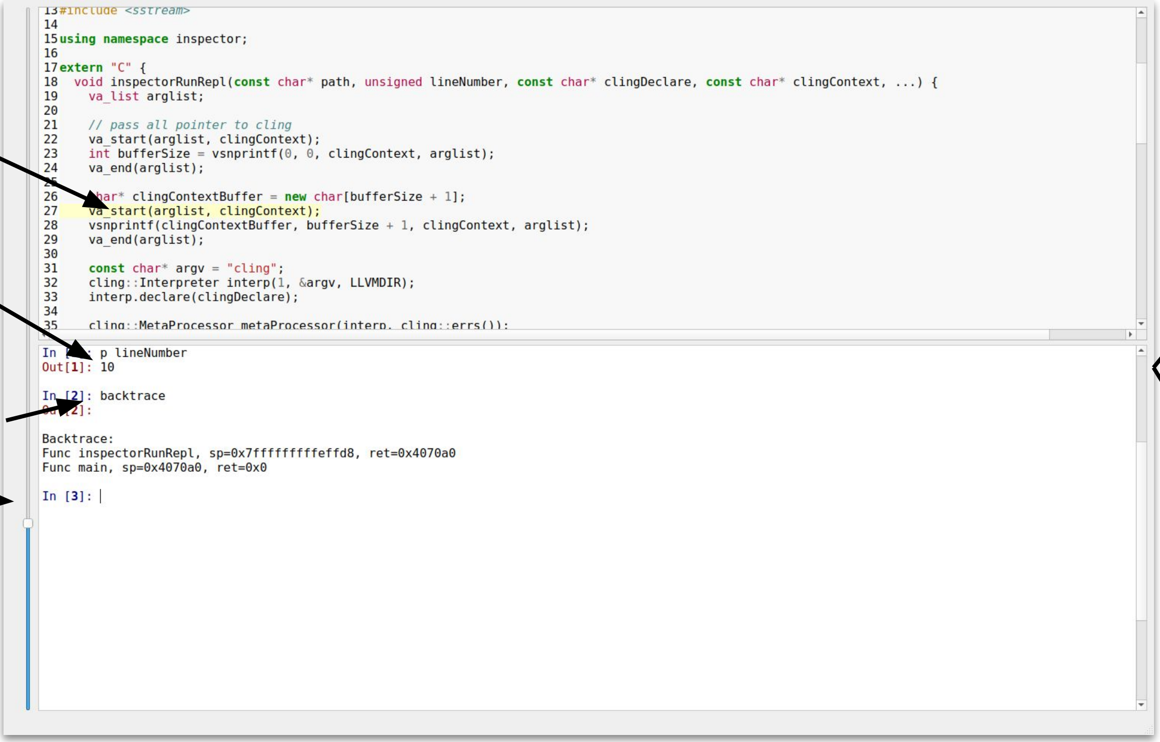
Phase #1: In-production monitoring



Phase #2: Replay debugging



HASE frontend



```
#include <sstream>

using namespace inspector;

extern "C" {
  void inspectorRunRepl(const char* path, unsigned lineNumber, const char* clingDeclare, const char* clingContext, ...) {
    va_list arglist;

    // pass all pointer to cling
    va_start(arglist, clingContext);
    int bufferSize = vsnprintf(0, 0, clingContext, arglist);
    va_end(arglist);

    char* clingContextBuffer = new char[bufferSize + 1];
    va_start(arglist, clingContext);
    vsnprintf(clingContextBuffer, bufferSize + 1, clingContext, arglist);
    va_end(arglist);

    const char* argv = "cling";
    cling::Interpreter interp(1, &argv, LLVMDIR);
    interp.declare(clingDeclare);

    cling::MetaProcessor metaProcessor(interp, cling::errs());
```

```
In [1]: p lineNumber
Out[1]: 10

In [2]: backtrace
Out[2]:

Backtrace:
Func inspectorRunRepl, sp=0x7ffffffffeffd8, ret=0x4070a0
Func main, sp=0x4070a0, ret=0x0

In [3]: |
```

Uses debug symbols

Evaluate expressions

Print backtrace

Timeslider

Angr

x86 machine code

HASE’s symbolic execution

- **Uses core dump**
  - Simplifies constraints by using concrete values from the core dump for the final state
- **Follows single path**
  - Avoids path explosion by following the processor trace snapshot
- **Lazy**
  - Does not compute all memory values, only those requested by the developer
- **Consistent**
  - Concrete values computed show to the developer are added as constraints to the session

Open challenges

- **Comprehensibility:**
    - Generate data values that help programmer to understand the problem

- **System model:**
    - Idea #1: Extend Angr’s system model
    - Idea #2: Full system tracing, symbolic or concrete execution of kernel code

- **Multi-threading:**
    - Processor trace has optional timestamps for partial ordering

Summary

- **Motivation:** Reproducing production bugs is difficult
  - Existing record/replay systems have high overheads

- **HASE:**
  - Replay debugging tool with low overhead
  - Combines symbolic execution and Intel PT
  - Operates on unmodified binary application code and kernel

- **Project page:** https://github.com/hase-project/hase