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Pinballs:

Portable and Shareable User-level Checkpoints for Reproducible Analysis and Simulation

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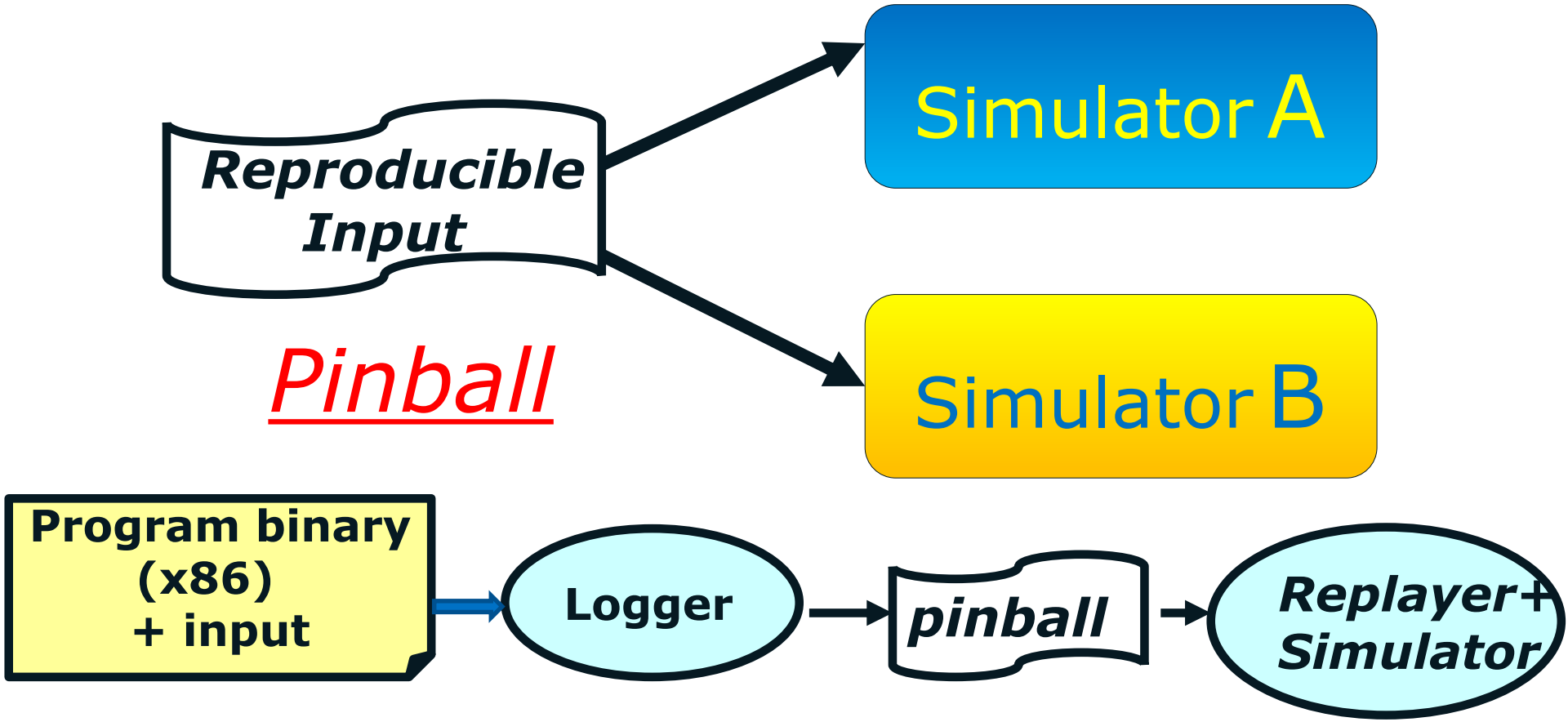
Objective : Reproducible Input for Simulators

Reproducible Input ➔ Apples to apples comparison



Check-pointing is not enough…Need to control non-determinism (Pinball does)

Single-threaded programs:

1. Changes to : Initial **stack/heap** addresss ; **shared library load location** (randomized address space)
2. Processor-specific instruction behavior changes: **CPUID, RDTSC**
3. **Signals** : Arbitrary memory/register/control-flow changes
4. **System call** behavior changes (depending on work-directory, environment variables: *gettimeofday() uname()*)

Multi-threaded programs: Shared-memory locations access order can change from run-to-run

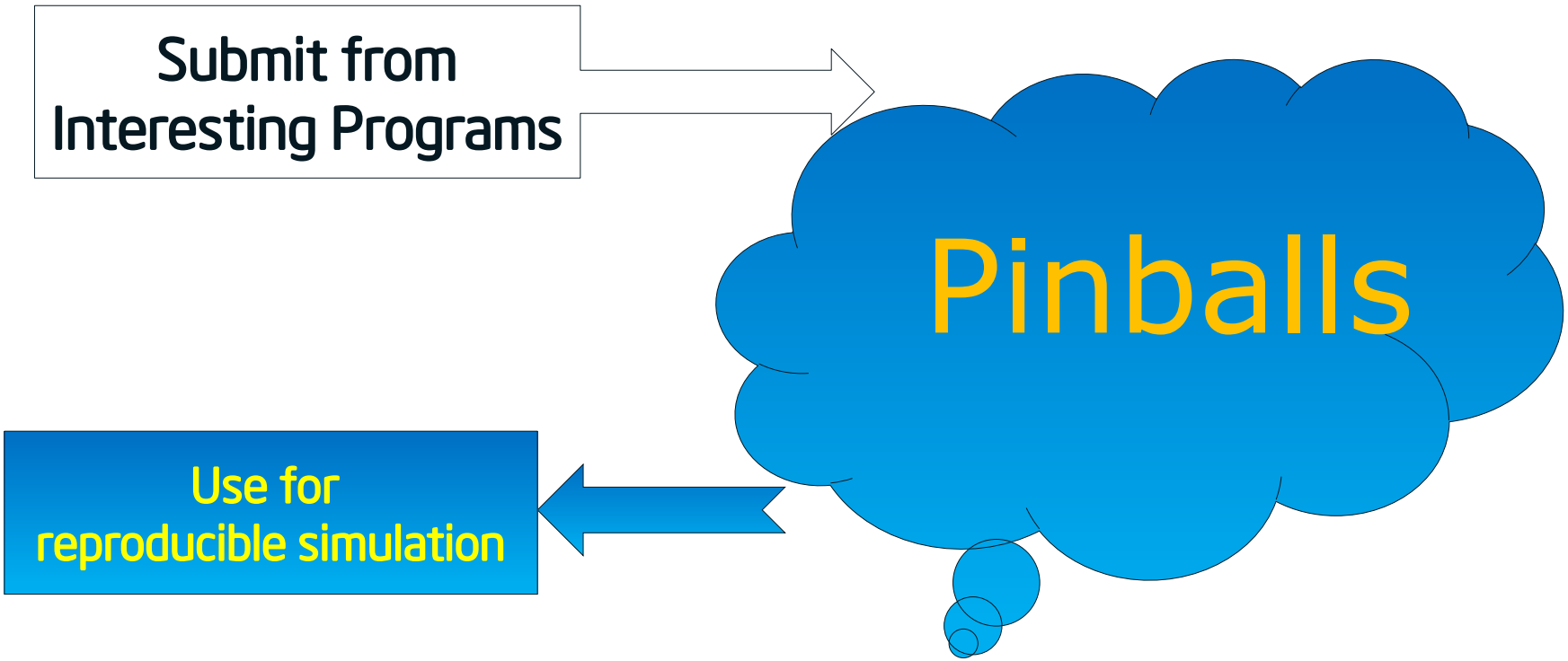
- **Accesses to locks/ mutexes**
  Different threads may "win" the race on different runs
- **OS scheduling**, load, machine configuration

Pinballs : Properties

- **Enable deterministic simulation : ST and MT**
  - See Trevor's talk on MT simulation
- **Independent of operating system (version/type)**
  - System call side-effects injected
- **Small in size**
  - Whole-program or regions

SPEC2006 (Average for 55 reference runs)	Instruction count	Pinball size	Logging slowdown (X native run-time)	Replay slowdown (X native run-time)
Whole-program	924 billion	39 MB	180X	20X
Region	130 million	12 MB		

The Vision: A Global Repository of Pinballs

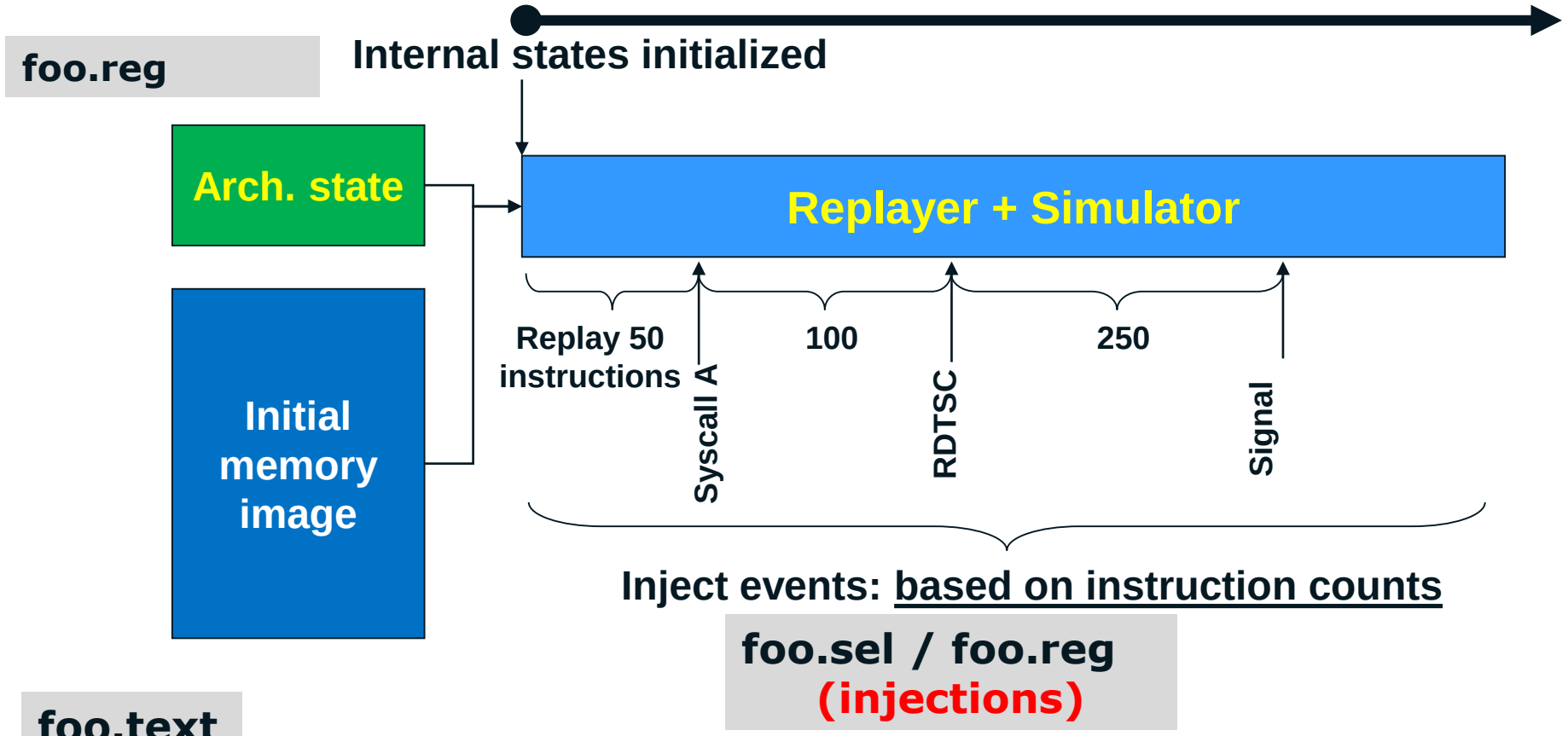


Started already (SPEC2006) :
http://snipersim.org/Pinballs

Outline

- Pinballs
  - **What are they?**
  - How are they generated?
  - How to use them for simulation?

Pinball (ST) = Initial memory/register + injections



- **System calls** : skipped by injecting next rip/ memory changed
- **CPUID, RDTSC** : affected registers injected
- **Signals/Callbacks** : New register state injected

Pinball (MT) : Pinball (ST) + Thread-dependencies

foo.reg (per-thread)

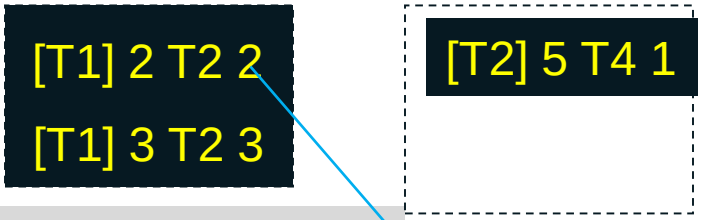
foo.text

Application Memory (common)

foo.reg (per-thread)

foo.sel (per-thread)

Event injection works only if same behavior (same instruction counts) is guaranteed during replay



Thread T2 cannot execute instruction 5 until T4 executes instruction 1

foo.race (per-thread)

Thread T1 cannot execute instruction 2 until T2 executes instruction 2

Outline

- Pinballs
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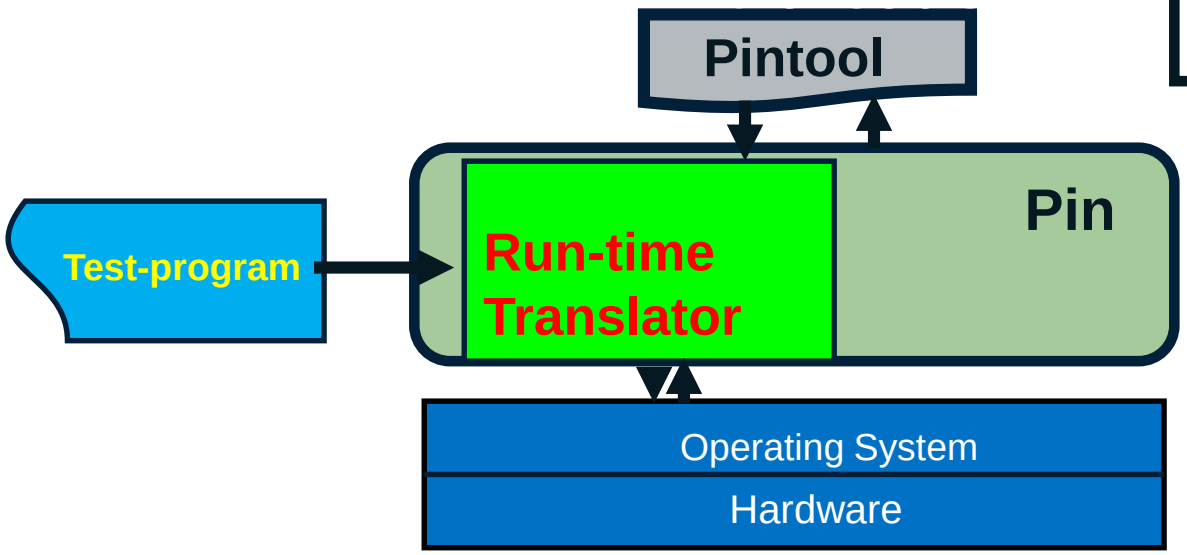
Pin: A Tool for Writing Program Analysis Tools

```
sub     $0xff, %edx
movl    0x8(%ebp), %eax
jle     <L1>
```

```
counter++; print(IP)
sub     $0xff, %edx
counter++; print(EA)
movl 0x8(%ebp), %eax
counter++;print(br_taken)
jle     <L1>
```




```
$ pin -t pintool -- test-program
```

Normal output
+ *Analysis output*

Pin: A Dynamic Instrumentation Framework from Intel
http://www.pintool.org

PinPlay: Workload Capture and Deterministic Replay Framework

Program/ Libraries

Input

License

Guaranteed Repeatability

No binaries/inputs

No application setup

No license checking

Record Once Replay + Analyze Multiple Times Anywhere!

Program Record/Replay Toolkit (Linux only) from Intel
http://www.pinplay.org

Outline

- Pinballs
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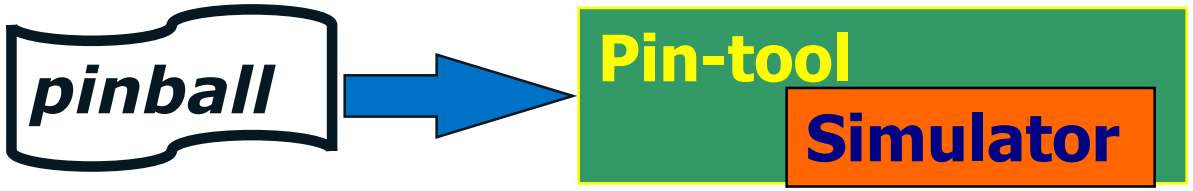
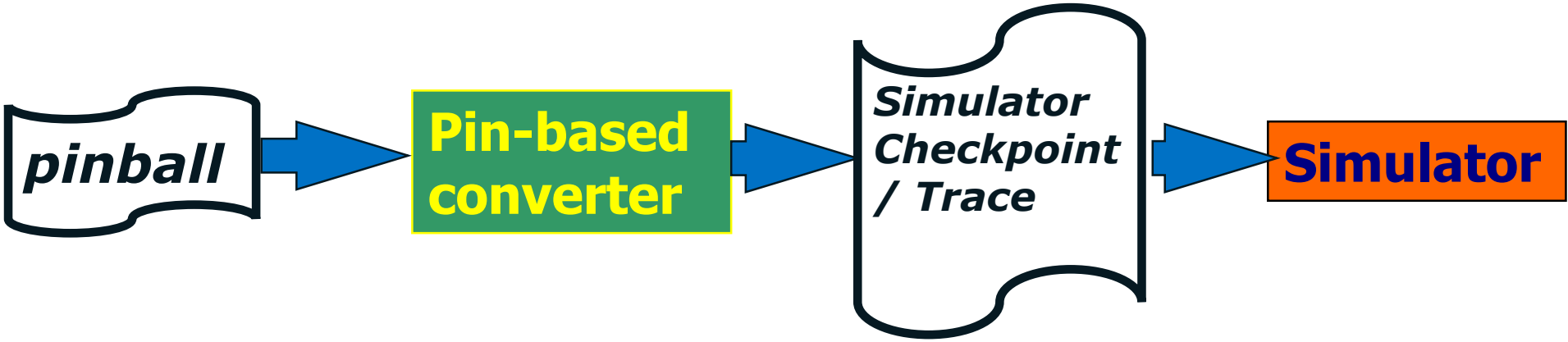
  - **How to use them for simulation?**

Pinball-based Simulation: Two Usage Models

1. Pin-based simulators: e.g. Sniper from Ghent Univ.



2. Other, non-Pin, simulators: e.g. Intel-internal
   Looking for collaboration : QEMU-based/ other simulators



Simulation Challenge + Solution

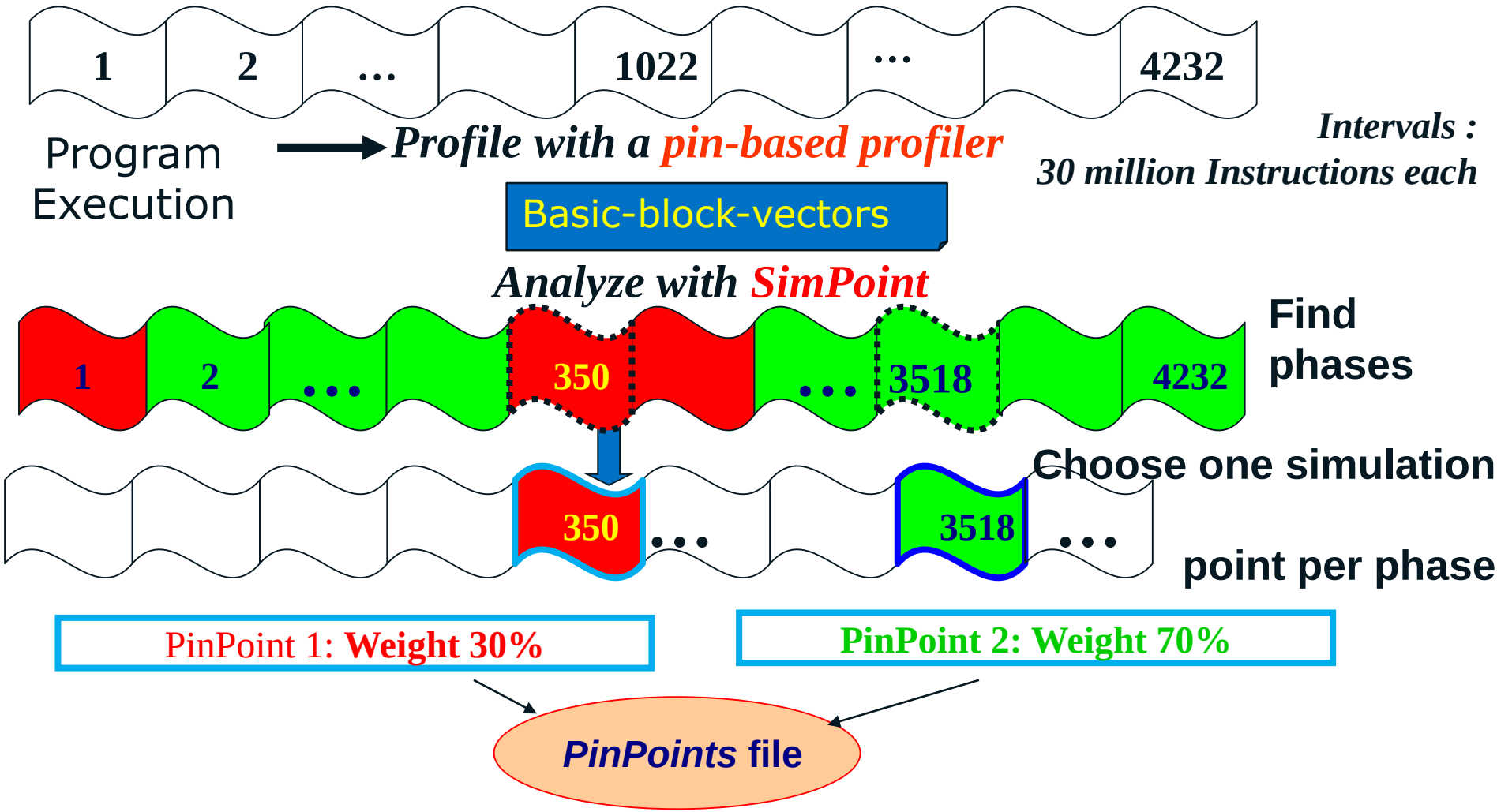
Detailed, cycle-accurate, simulation is slow

Solution: Find/simulate only representative regions (*PinPoints*)

- PinPoints cover << 1% of whole-program execution

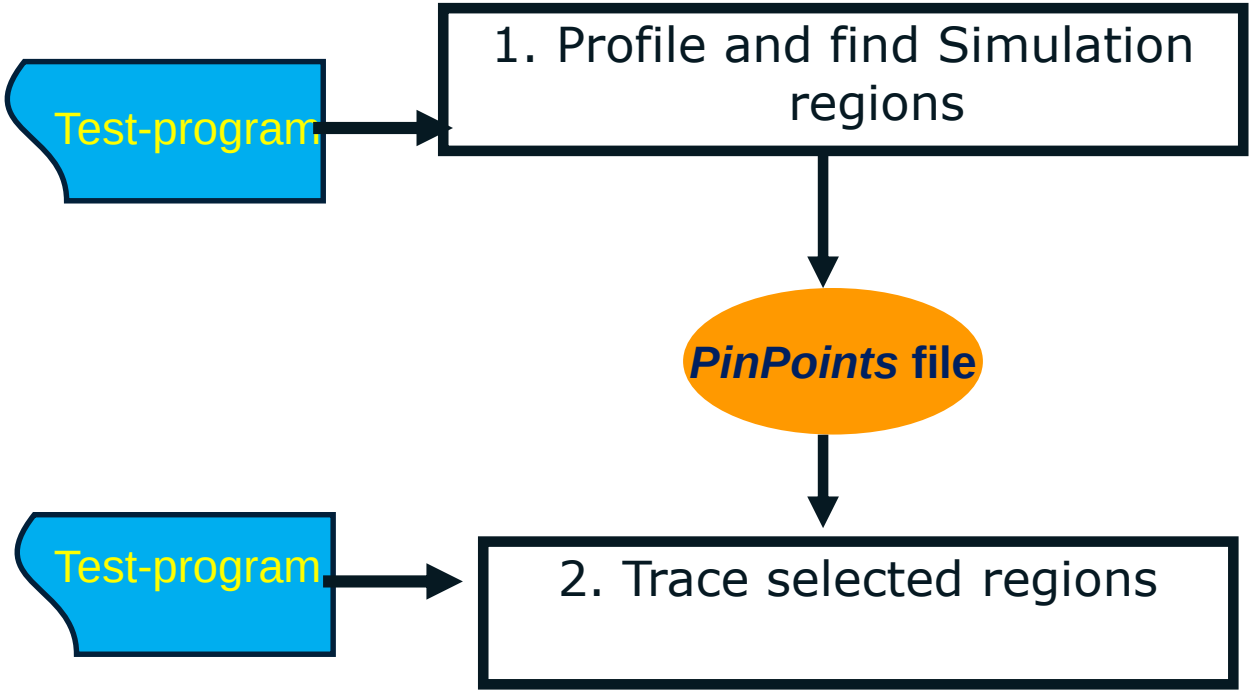
➔ **vastly reduced simulation time**

PinPoints = Pin + SimPoint (UC San Diego)



Two Phases => Two PinPoints

PinPoints : The Repeatability Challenge

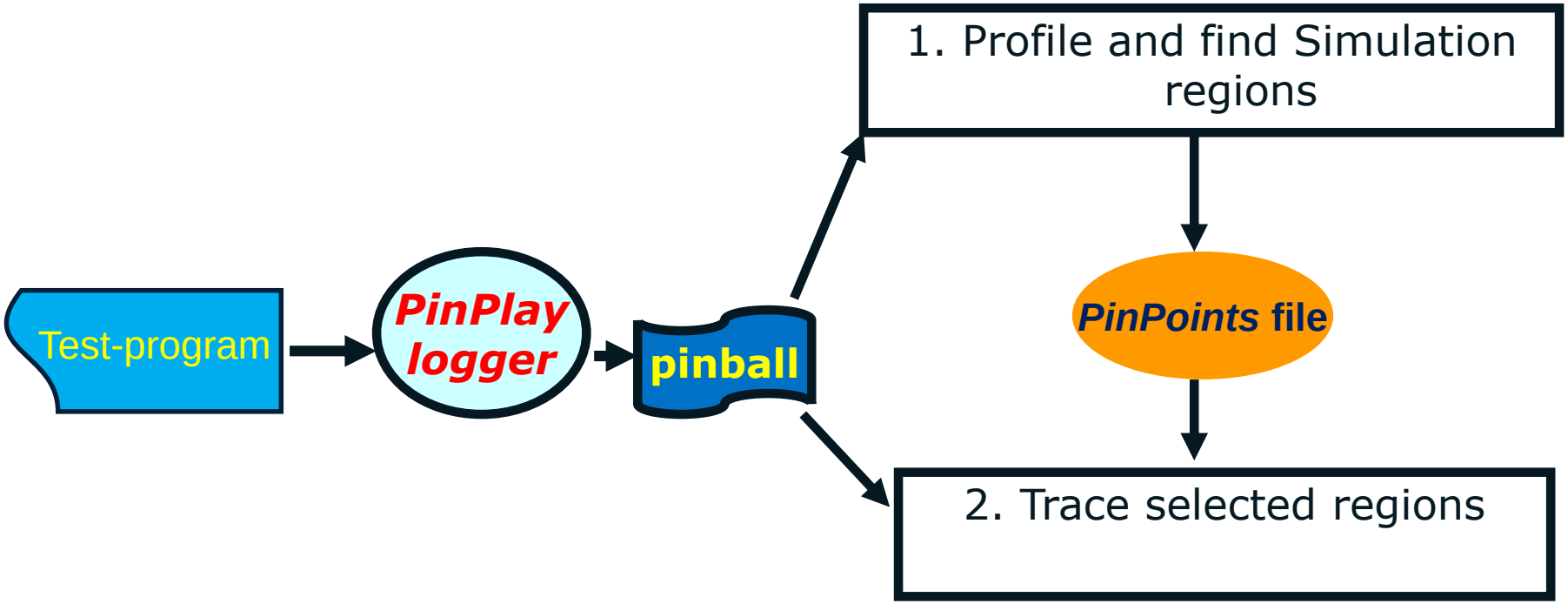


Problem: Two runs are not exactly same → PinPoints missed

Found this for 25/54 SPEC2006 runs!

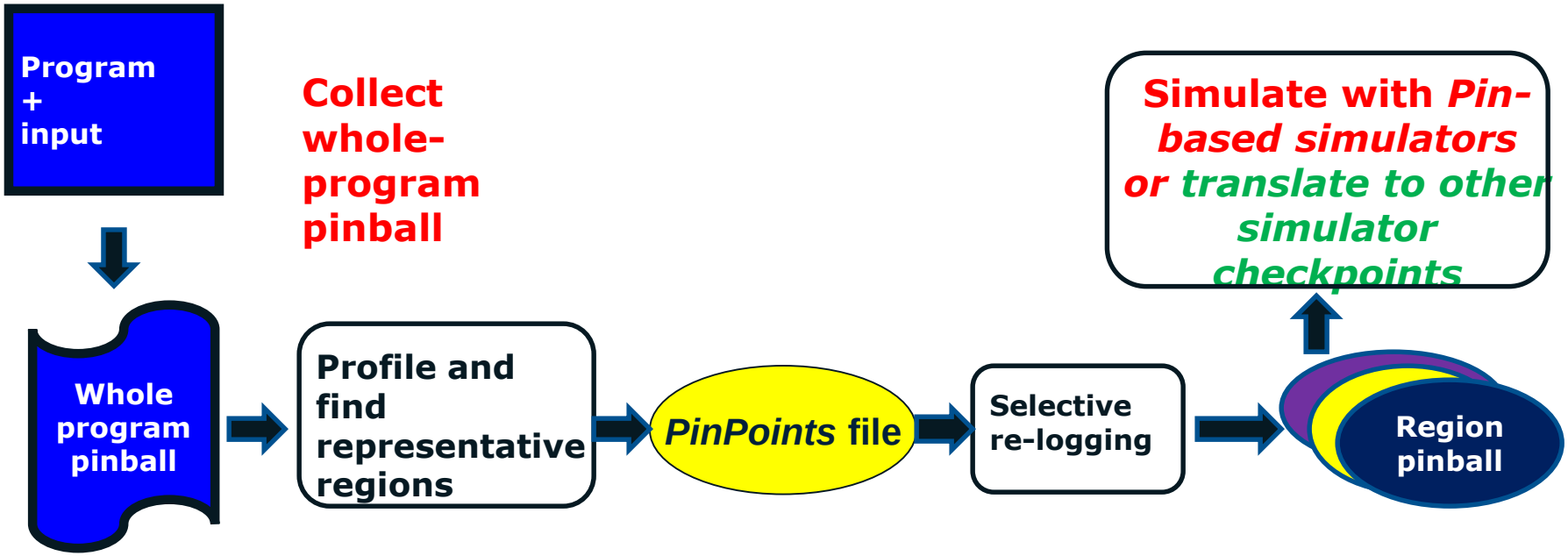
[*"PinPoints out of order" "PinPoint End seen before Start"*]

Enters PinPlay To Provide Repeatability



Two runs are same → PinPoints guaranteed to be reached

PinPlay + PinPoints: Basic Flow



- PinPoints are representative (validation/tuning possible)
- PinPoints cover << 1% of whole-program execution

➔ **vastly reduced simulation time**

SPEC : CPU2006 Pinballs for download www.snipersim.org/Pinballs

Pinballs

Download Pinballs for full runs and PinPoints

SPEC CPU 2006

- Pinballs in Pinplay 1.1 format (Sniper 5.2+)
  - Whole program pinballs
    - Download 2.1 GiB (md5)
  - PinPoints
    - Download 2.1 GiB, no warmup, 1B instruction detailed region, maxK=1 (md5)
    - Download (p1/md5, p2/md5, p3/md5, p4/md5) 6.9 GiB, 100M instruction warmup, 30M instruction detailed region,

Summary : Pinballs

User-level x86 checkpoints:

1. Enable deterministic simulation
2. Portable : No OS dependence
3. Shareable : Relatively small in size

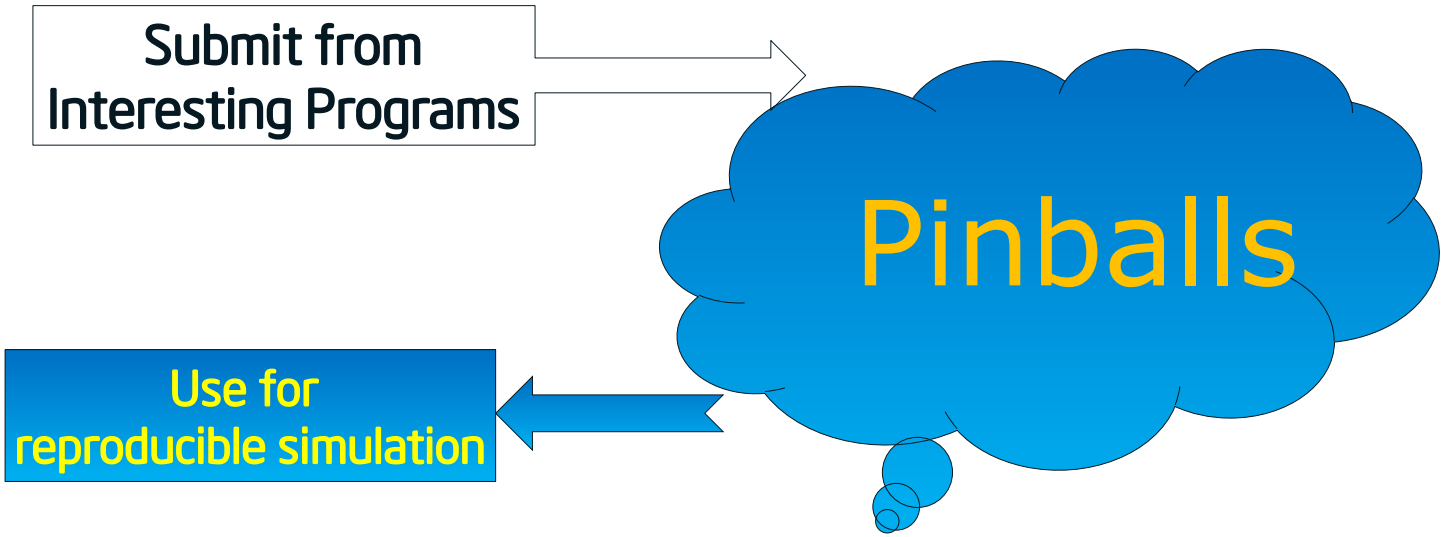
Generate with PinPlay : http://www.pinplay.org

Use for simulation:

1. Replay-enabled Pin-based simulator OR
   Translate to other simulator inputs
2. Whole-program or representative regions (*PinPoints*)

Call for action

1. Make a global repository a reality



2. Pinball converter for QEMU-based/other simulators

Upcoming Events

1. **Use of Pinball for debugging**:

DrDebug: CGO 2014 talk (Monday 2/17/2014) @4 PM

15:15PM-16:30PM Session 3: Tools for Program Introspection

DrDebug: Deterministic Replay based Cyclic Debugging with Dynamic Slicing

Yan Wang (UC Riverside), Harish Patil, Cristiano Pereira, Gregory Lueck (Intel Corporation), Rajiv Gupta, Iulian Neamtiu (UC Riverside)

2. **Creation of Pinballs for representative regions**:

PinPoints: ISCA 2014 tutorial (Sunday 15th June, 2014)

- T7: PinPoints: Simulation Region Selection with PinPlay and Sniper (morning)

(https://sites.google.com/site/pinpointstutorialisca14/)