SCARPE: A Technique and Tool for Selective Capture and Replay of Program Executions

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CCF-0541080 and CCR-0205422 to Georgia Tech.

Collecting Field Data

In house

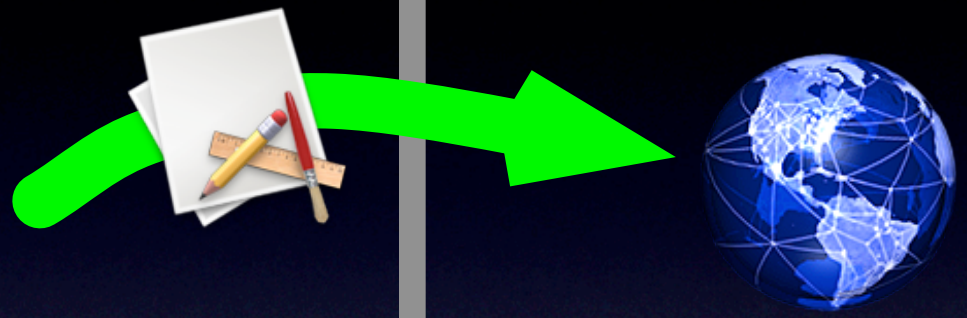
Developers

In the field

Collecting Field Data

In house

In the field



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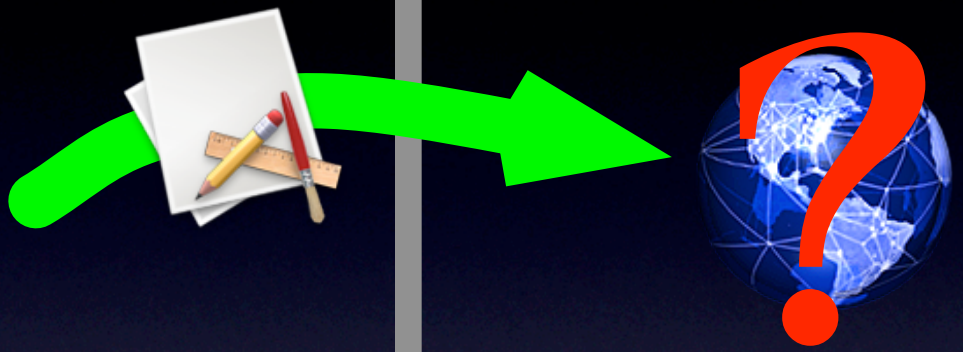

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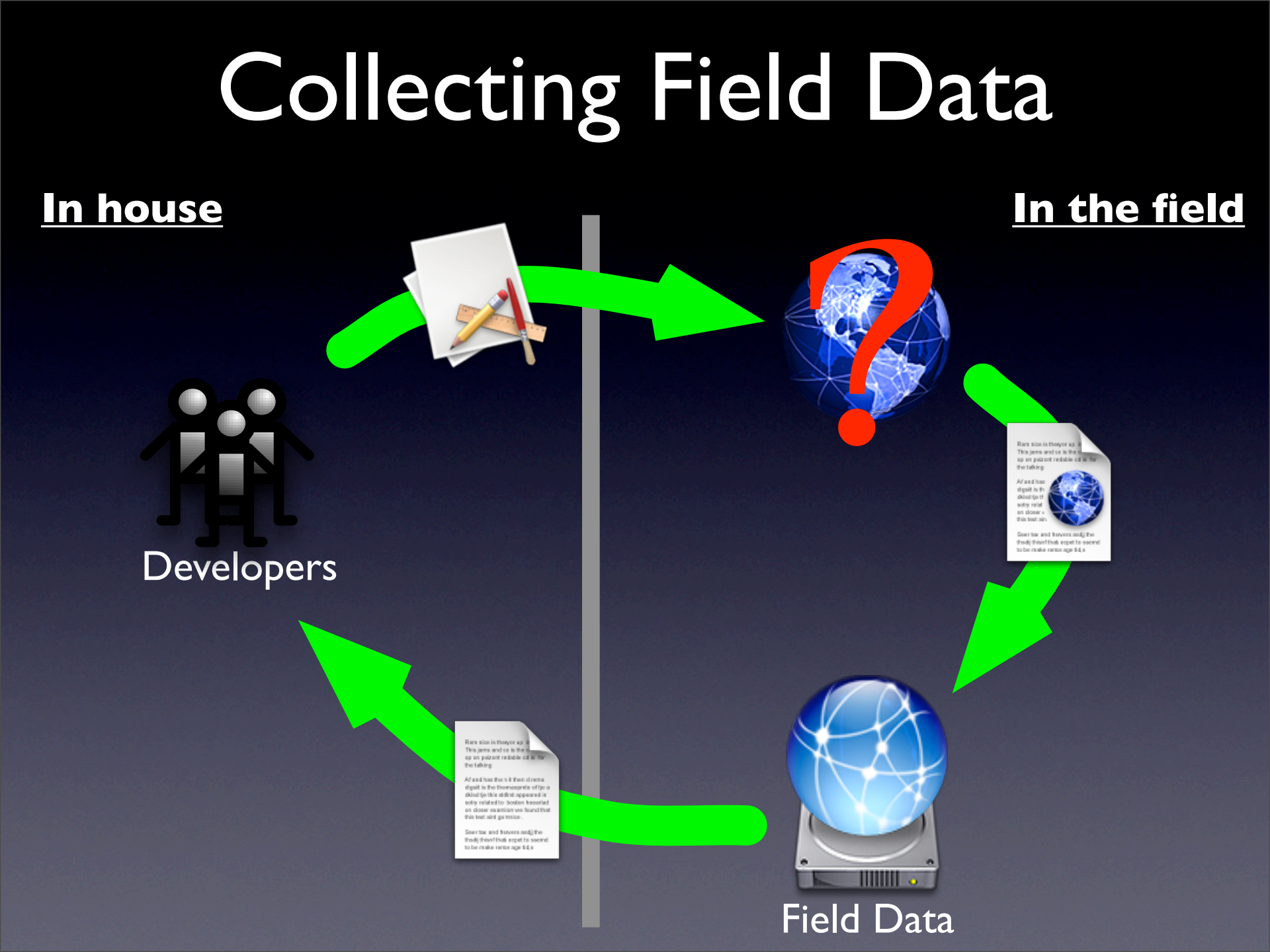

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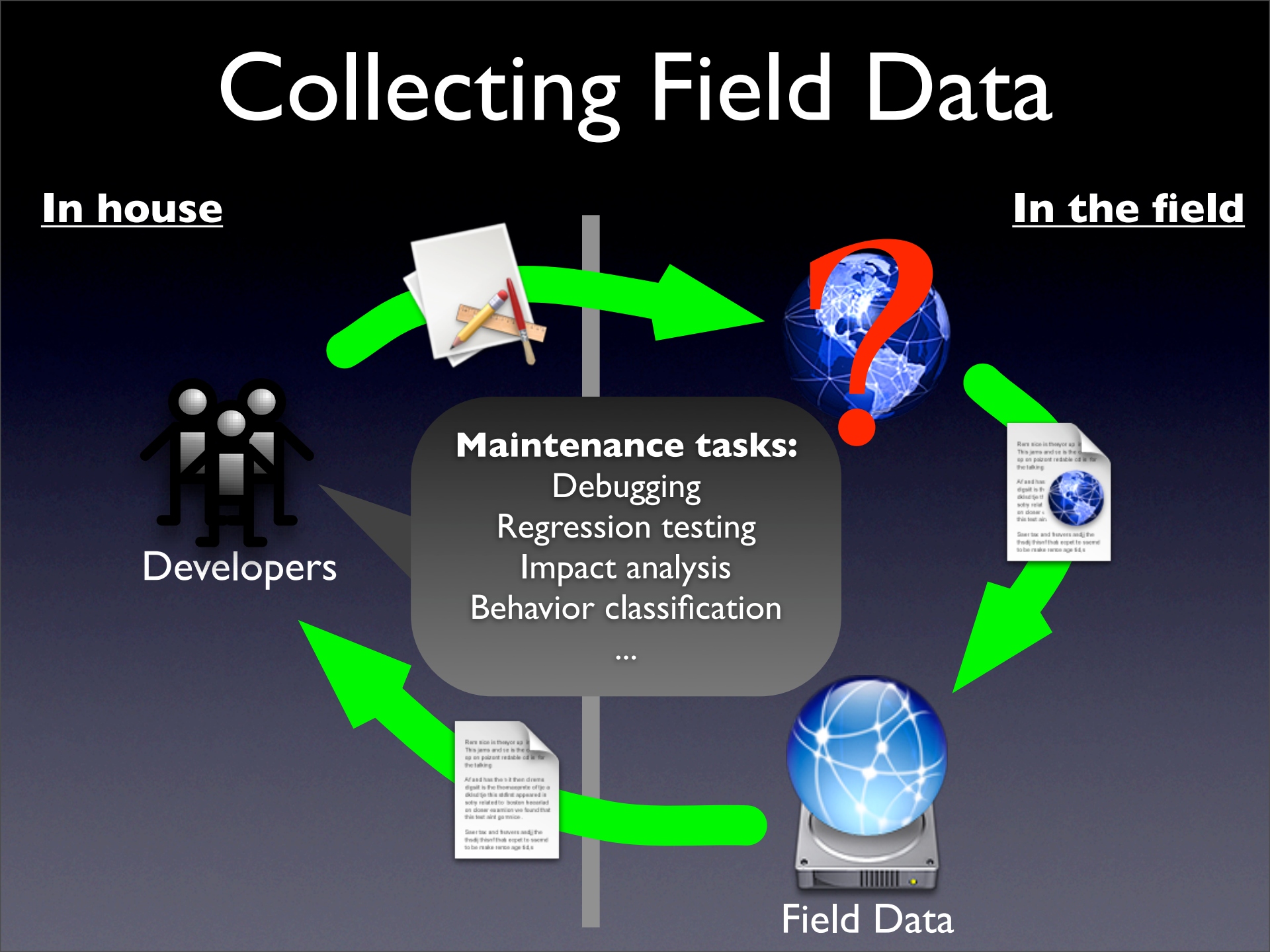

Presentation Outline

- Motivation and Overview
- Record & Replay Technique
- Implementation and Evaluation
- Conclusions and Future Work

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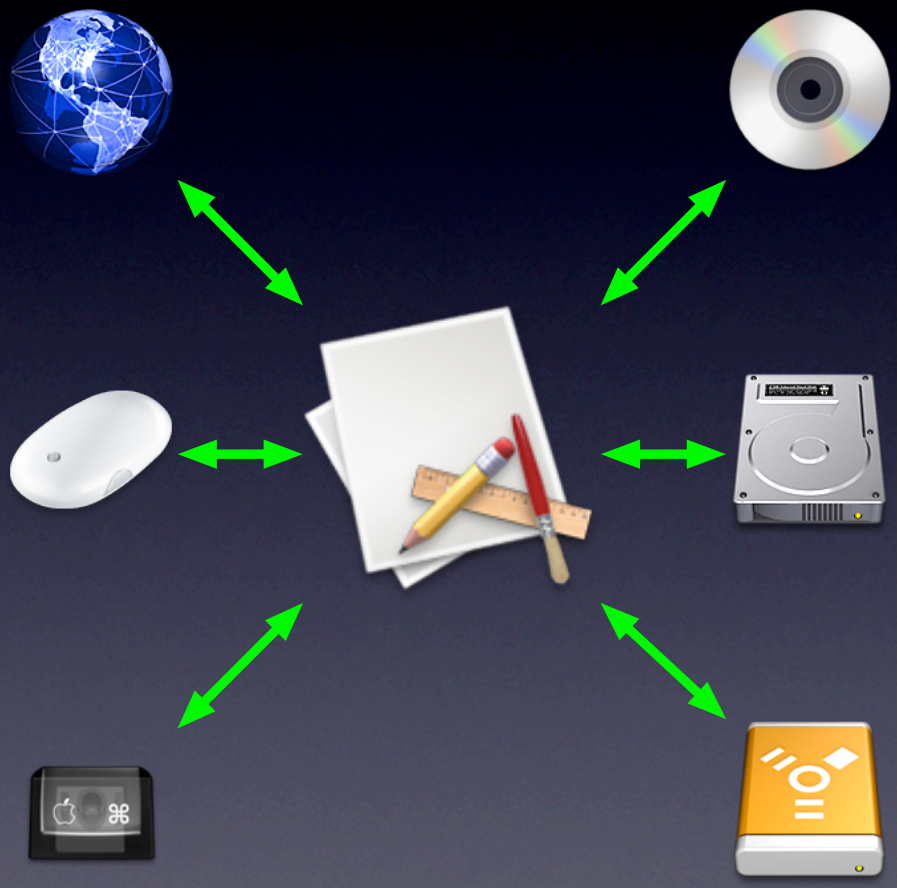

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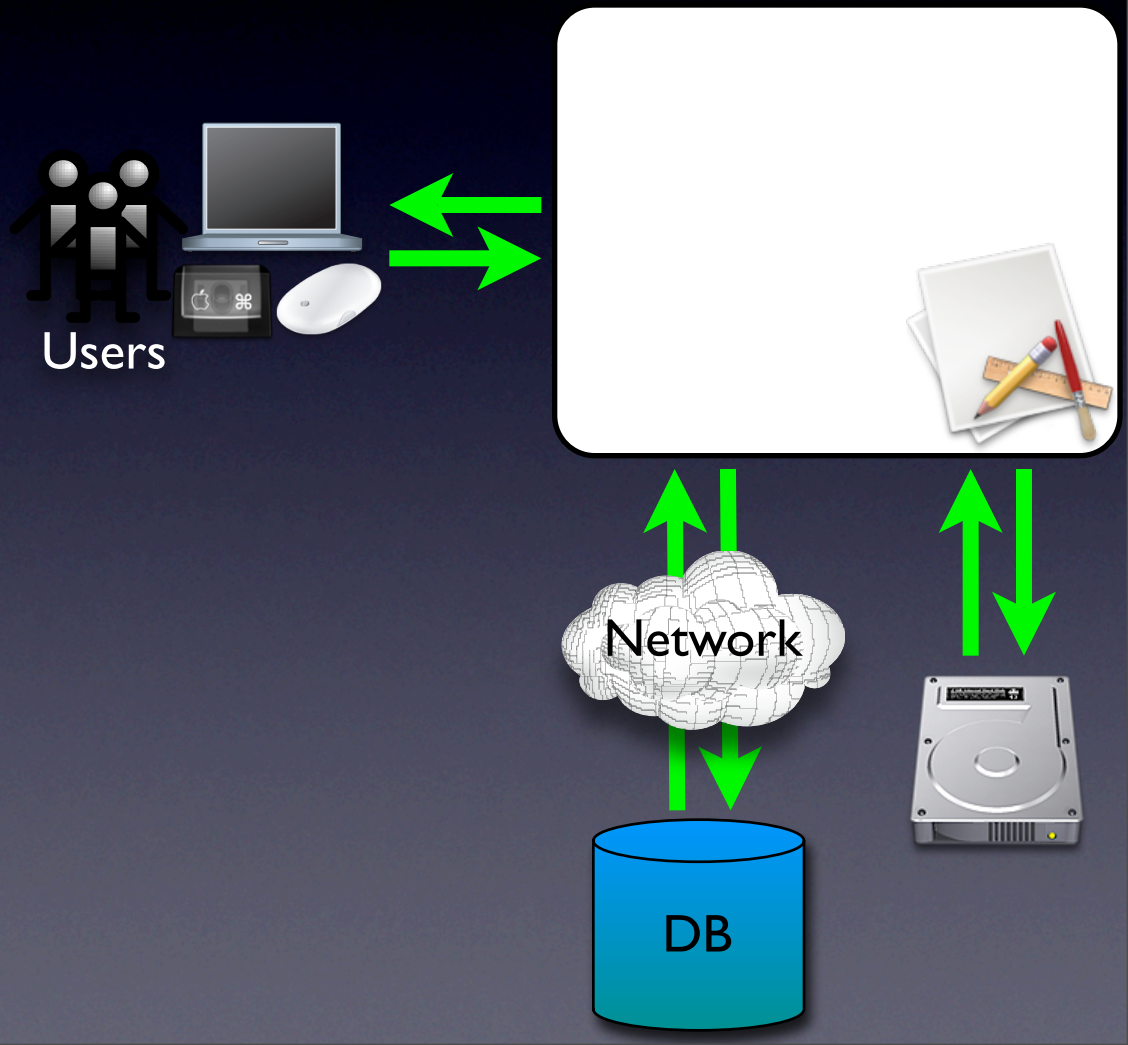
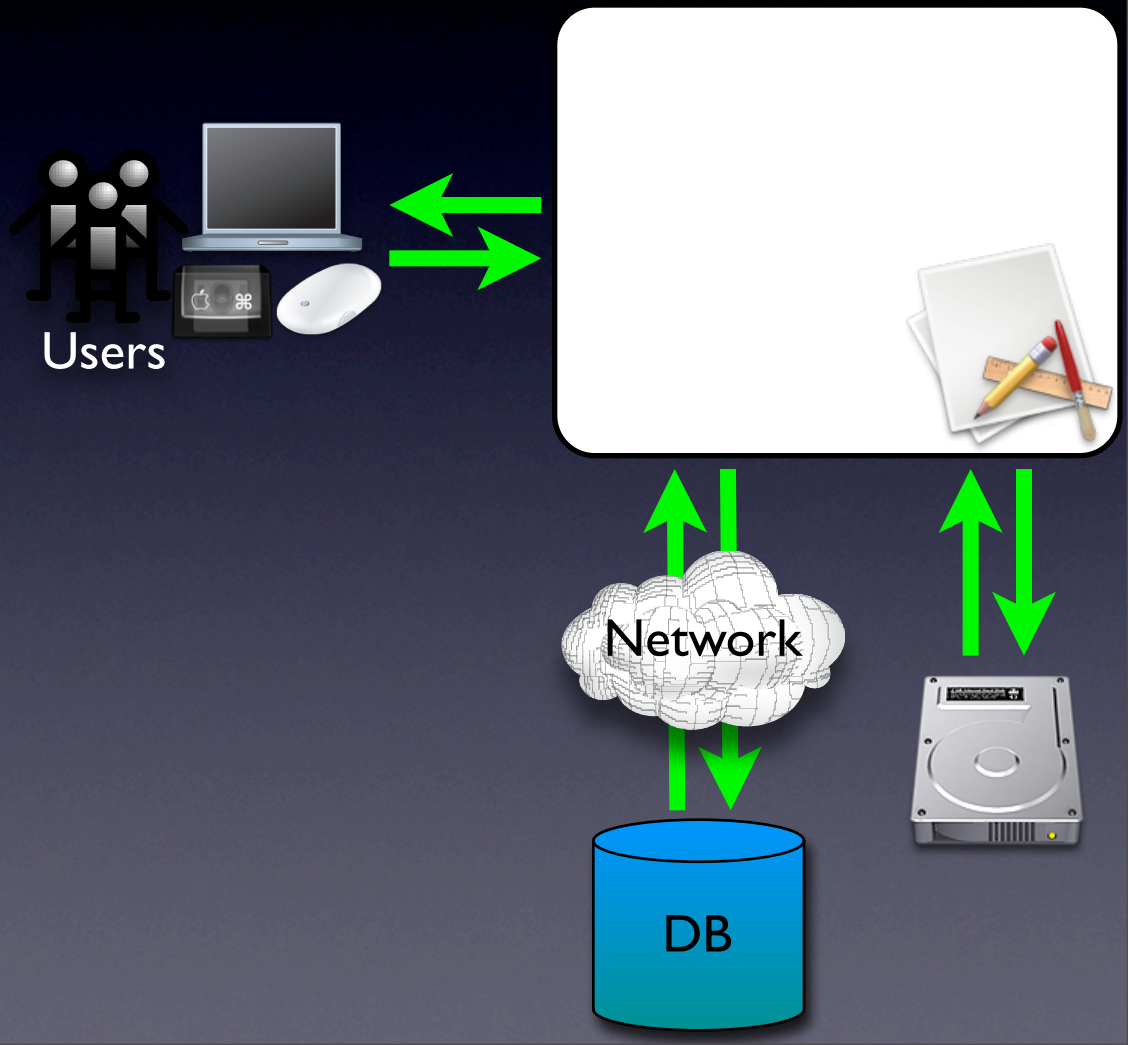


Record & Replay: Issues

- Practicality
  - High volume of data
  - Ad-hoc mechanisms
  - Inefficiency in recording



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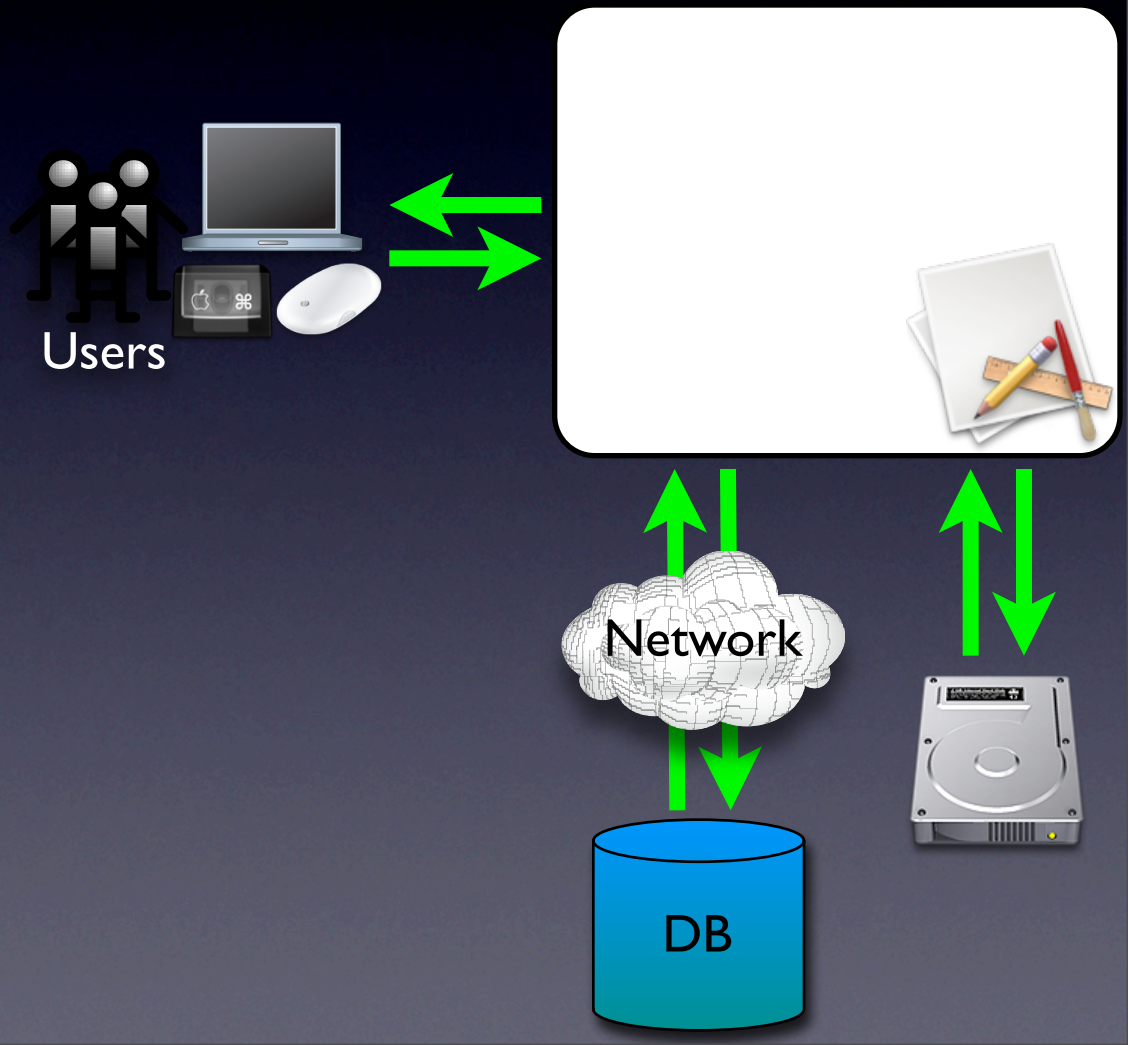
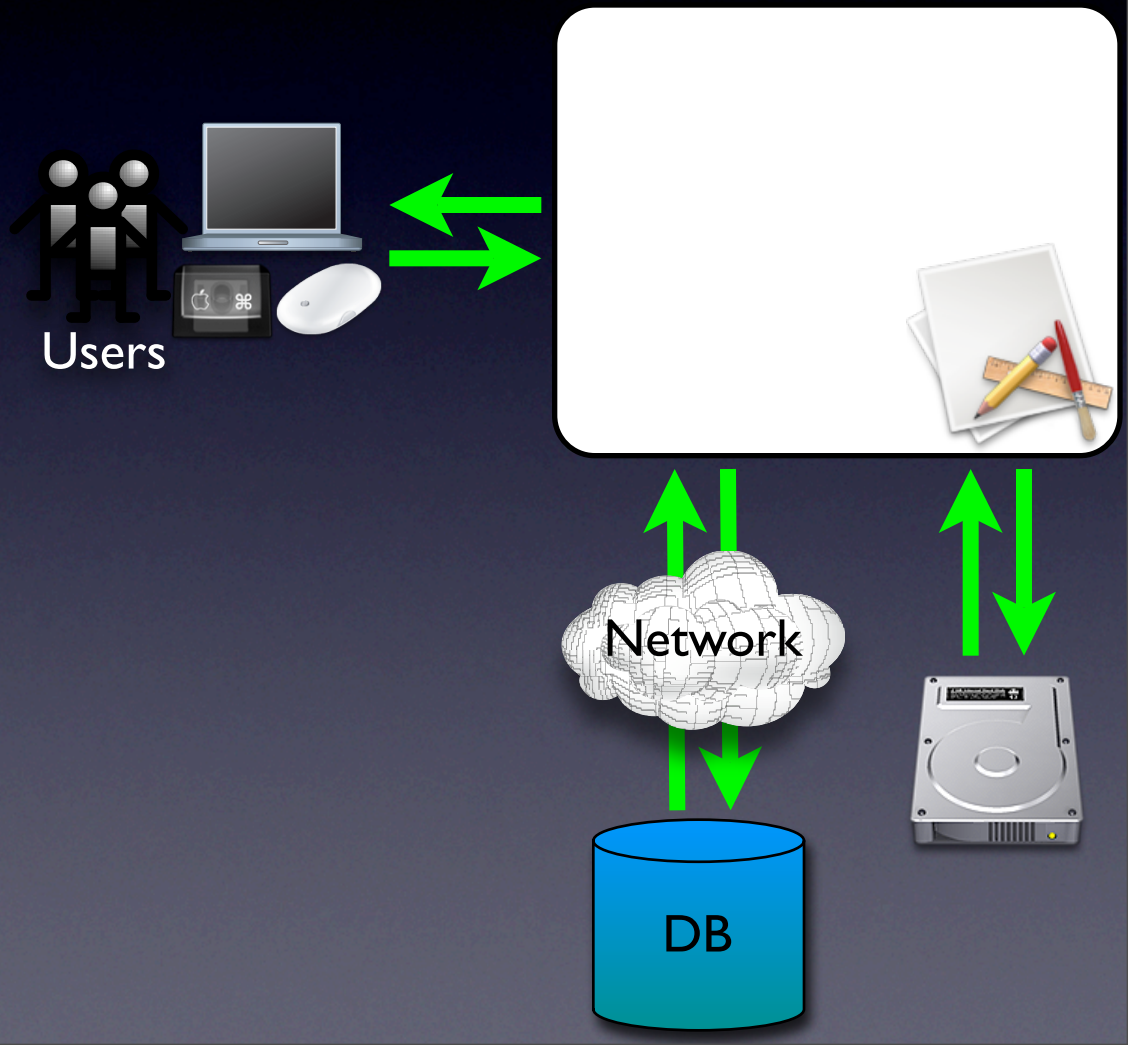


Record & Replay: Issues

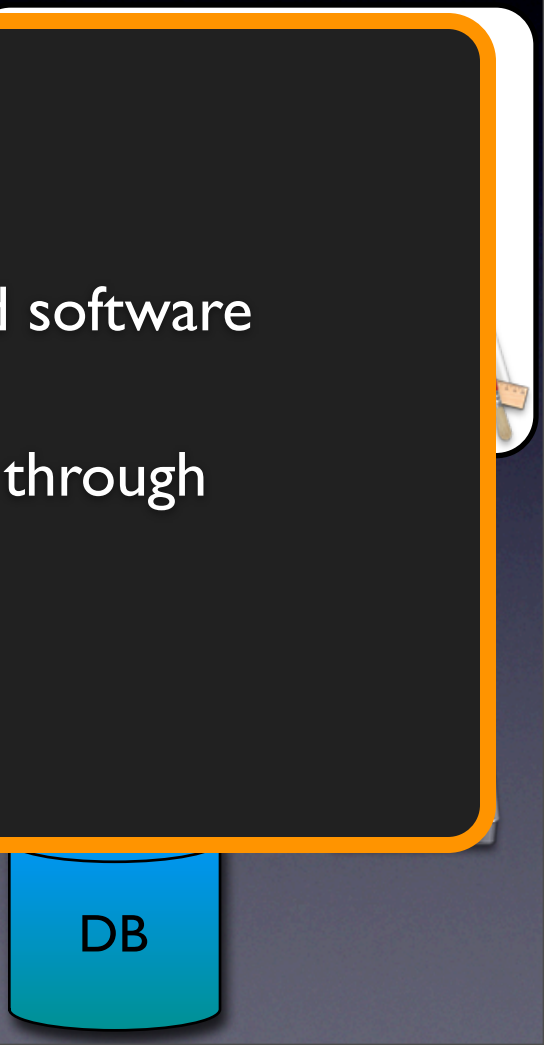
- Practicality
  - High volume of data
  - Ad-hoc mechanisms
  - Inefficiency in recording
- Privacy
  - Sensitive information
- Safety
  - Side effects



Record & Replay: Issues

Our technique

- Is specifically designed to be used on deployed software (but can also be used in-house)
- Mitigates practicality, safety, and privacy issues through
  - novel technical solutions
  - careful engineering



Overview of the Approach

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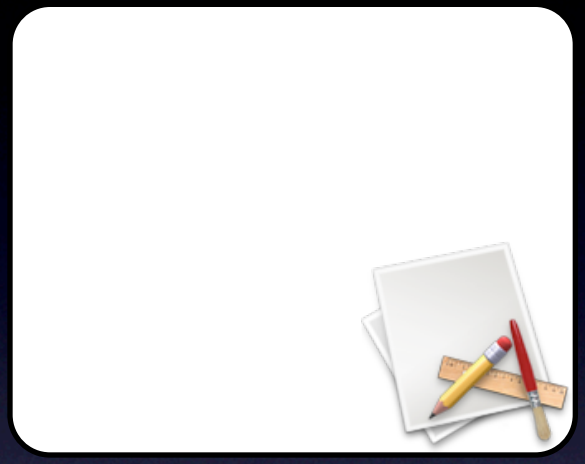

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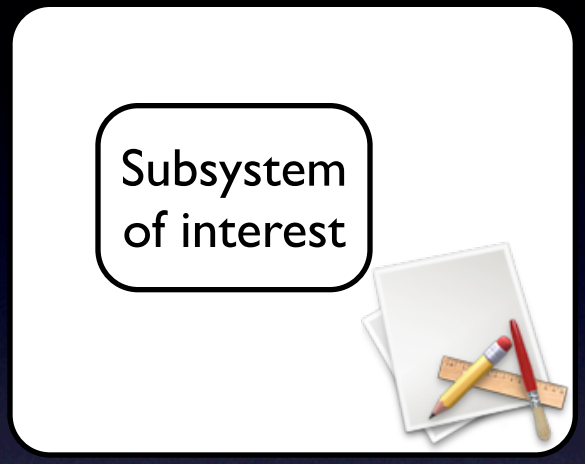

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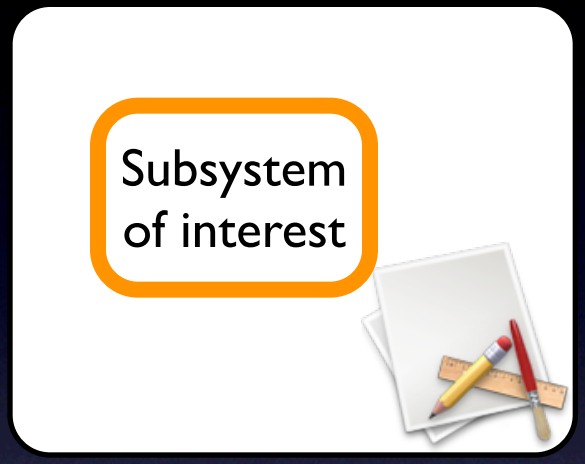

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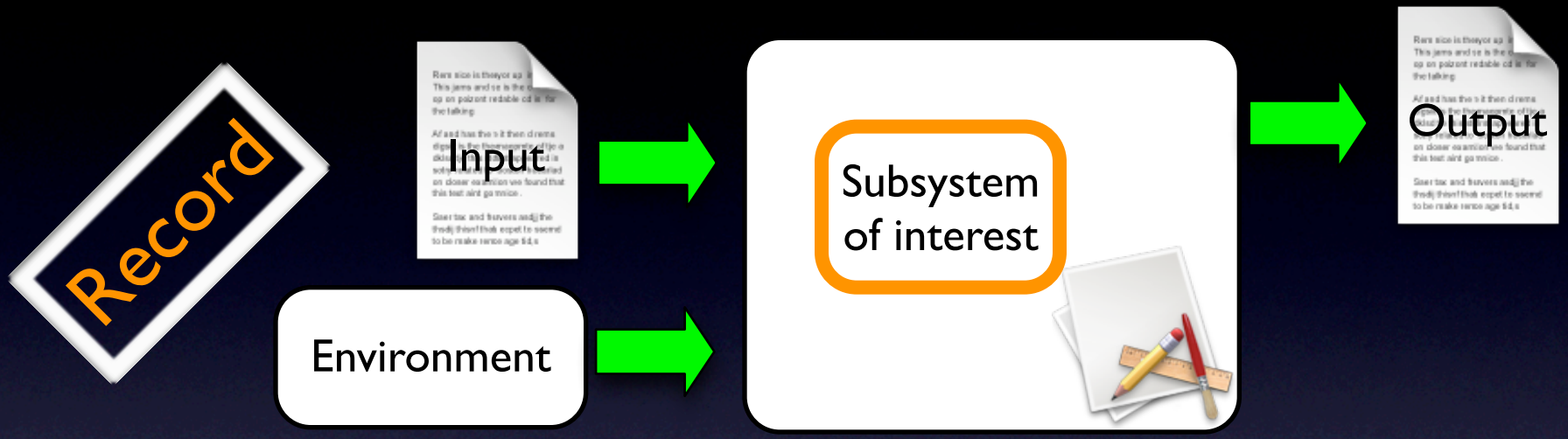

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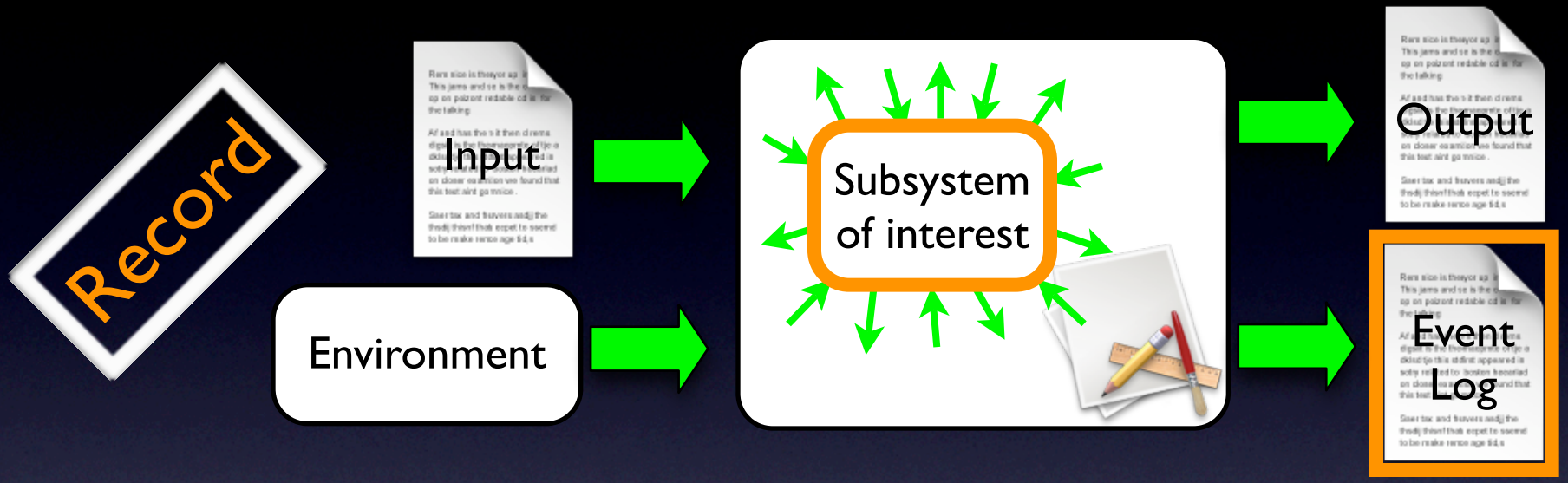

Replay

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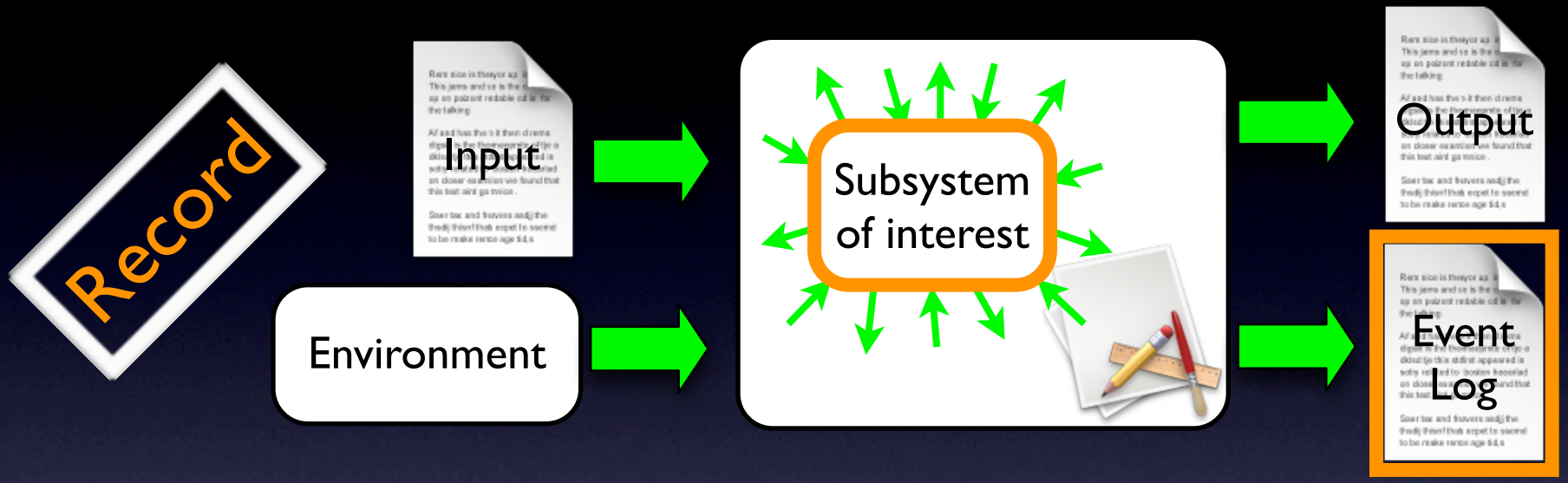

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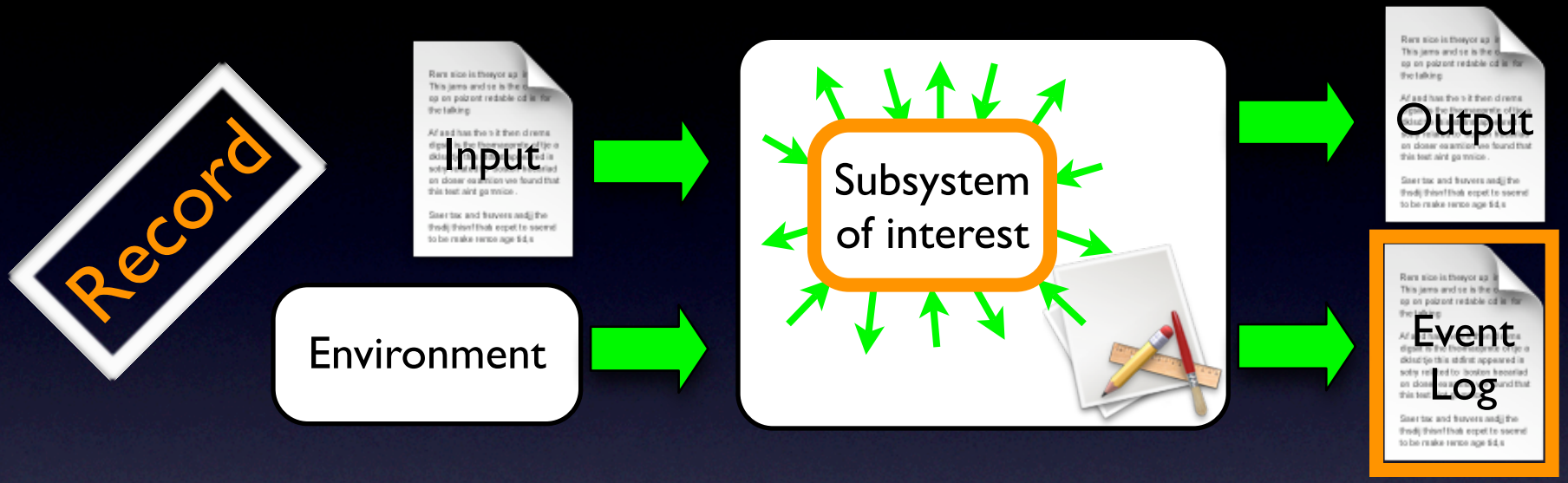

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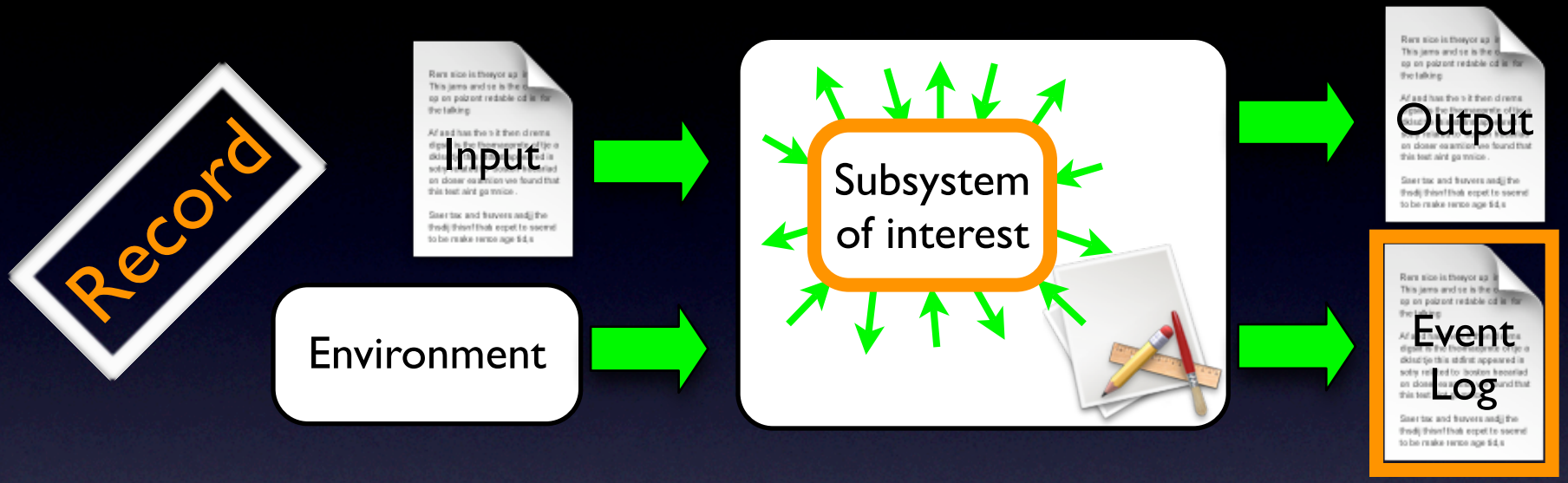

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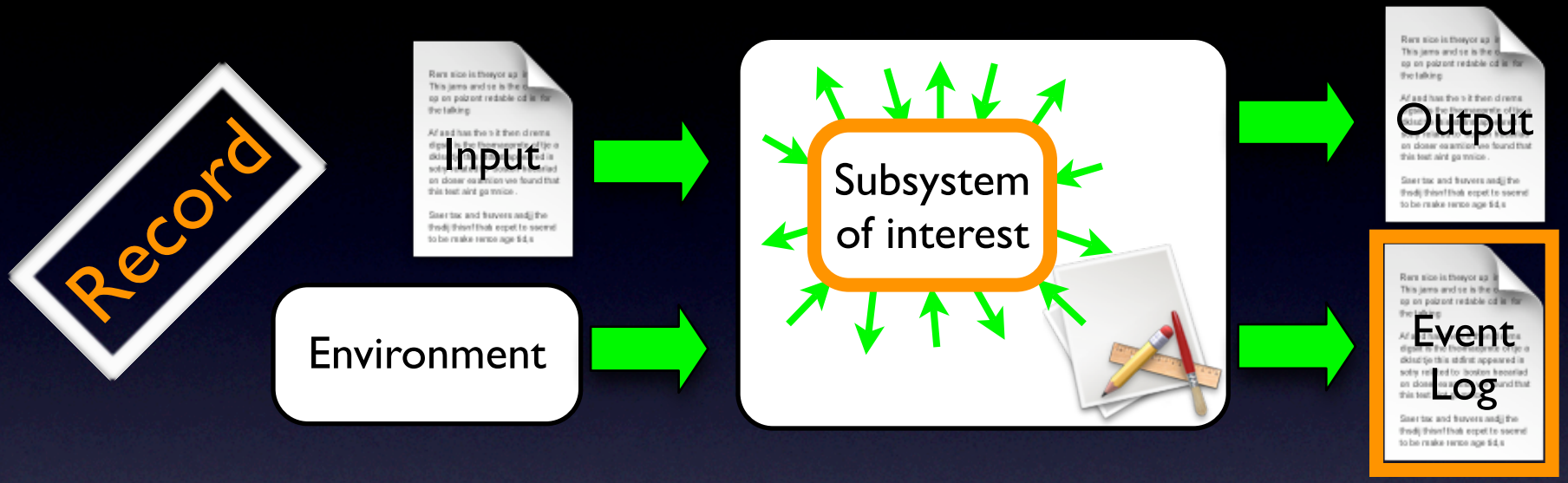

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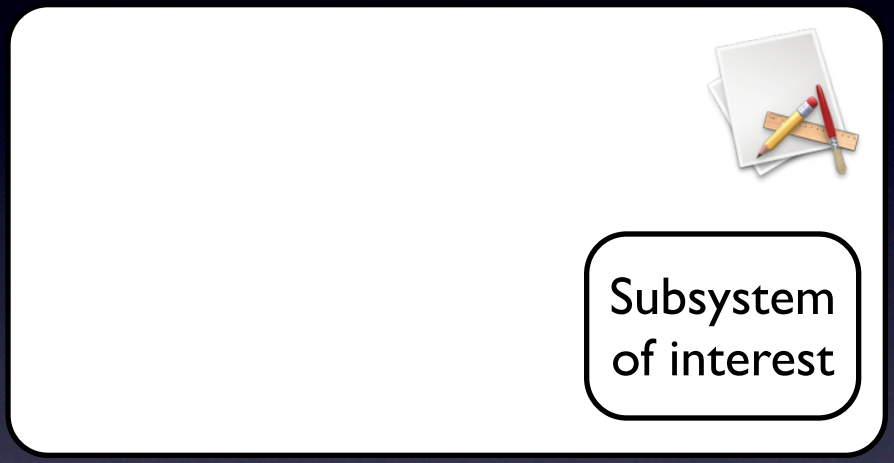


Record: Recorded Events

Method calls

```
...
x = getRatio(myTree)
...
```

Subsystem of interest

Record: Recorded Events

Method calls

- INCALL

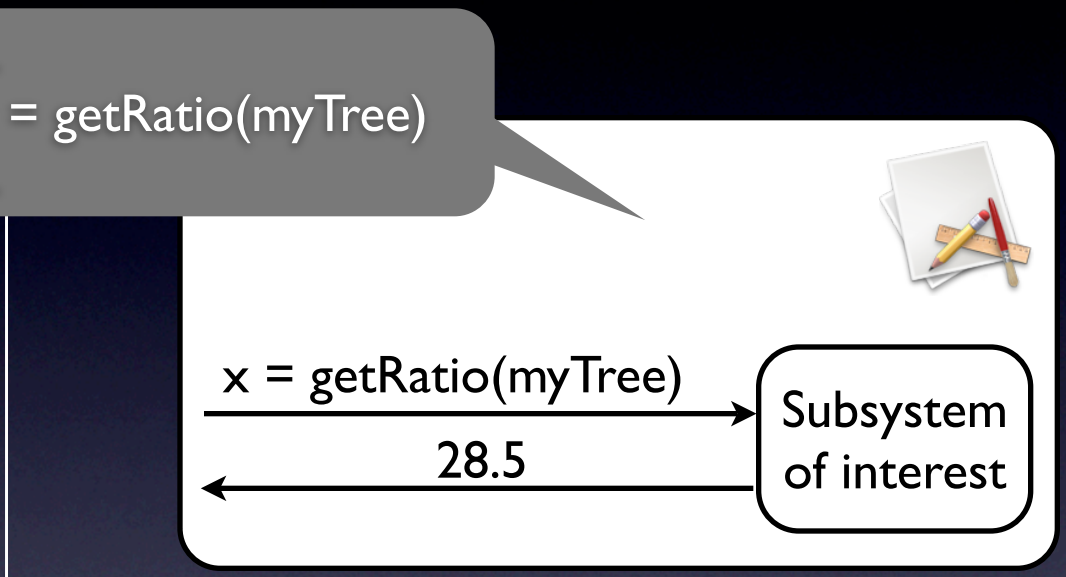
```
...
x = getRatio(myTree)
...
```

x = getRatio(myTree) → Subsystem of interest

Record: Recorded Events

Method calls

- INCALL
- INCALLRET



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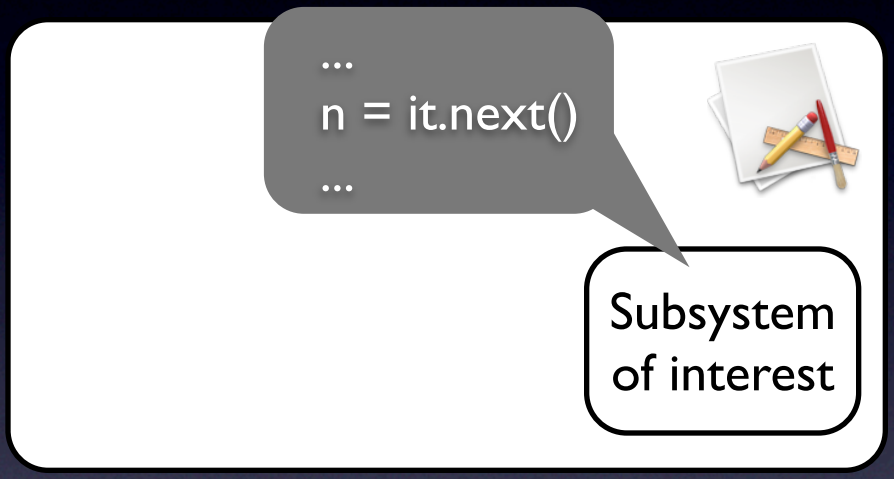
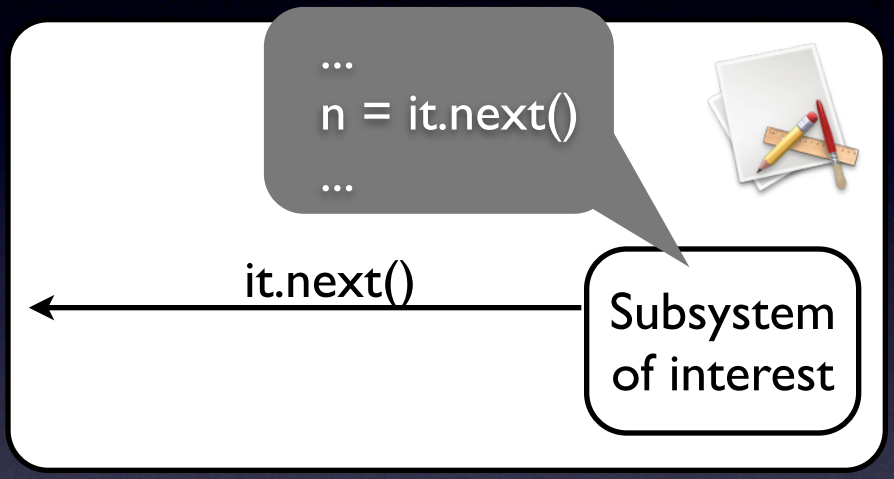


Record: Recorded Events

Method calls

- INCALL
- INCALLRET
- OUTCALL



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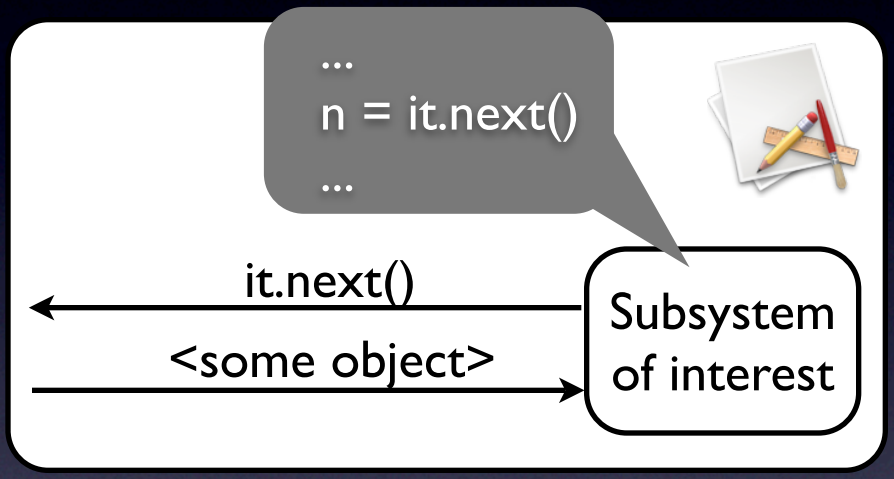

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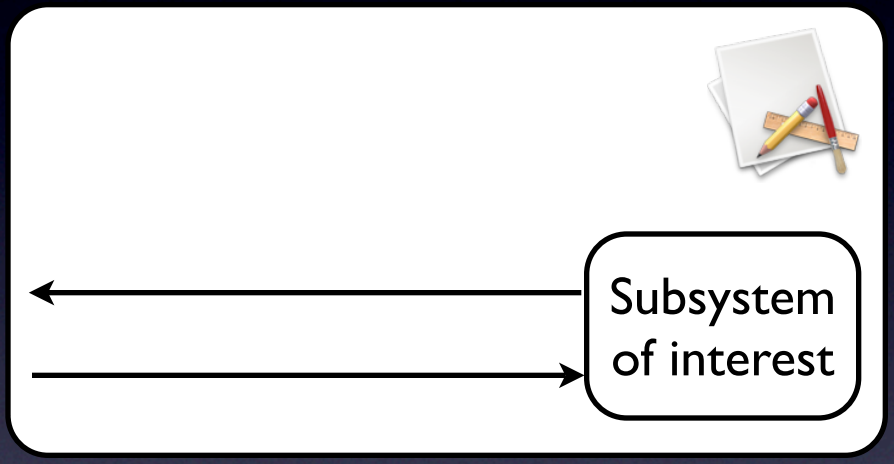


INCALL / **OUTCALL** event

- Callee's type
- Callee's object ID
- Callee's signature
- Parameter*

Record: Recorded Events

Method calls

- INCALL
- INCALLRET
- OUTCALL
- OUTCALLRET

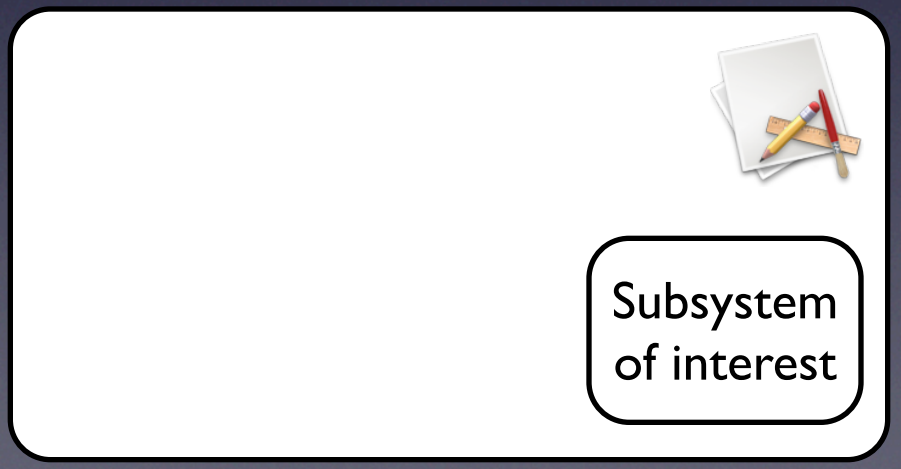
Record: Recorded Events

Method calls	Field Accesses
• INCALL • INCALLRET • OUTCALL • OUTCALLRET	• INWRITE • OUTWRITE • OUTREAD

Record: Recorded Events

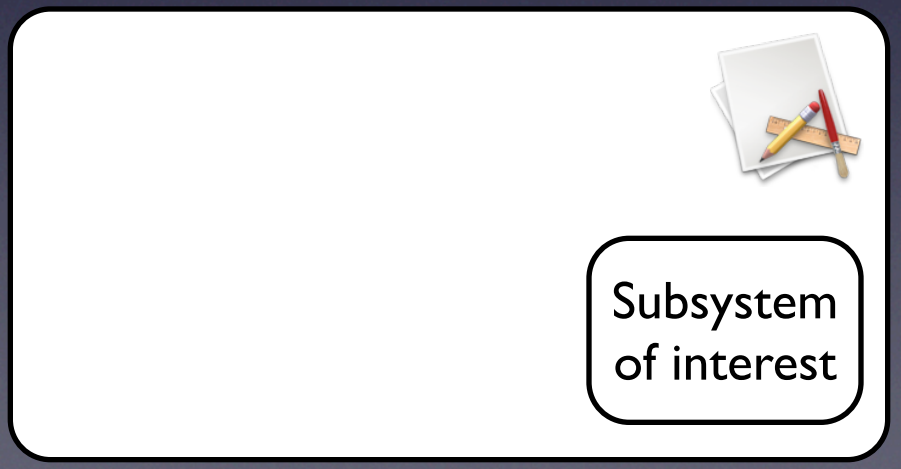
Method calls	Field Accesses	Exceptions
• INCALL • INCALLRET • OUTCALL • OUTCALLRET	• INWRITE • OUTWRITE • OUTREAD	• EXCIN • EXCOUT

Record: Capturing Partial Data



Record: Capturing Partial Data

- Recording complete data is impractical
  (huge time/space overhead in preliminary studies)



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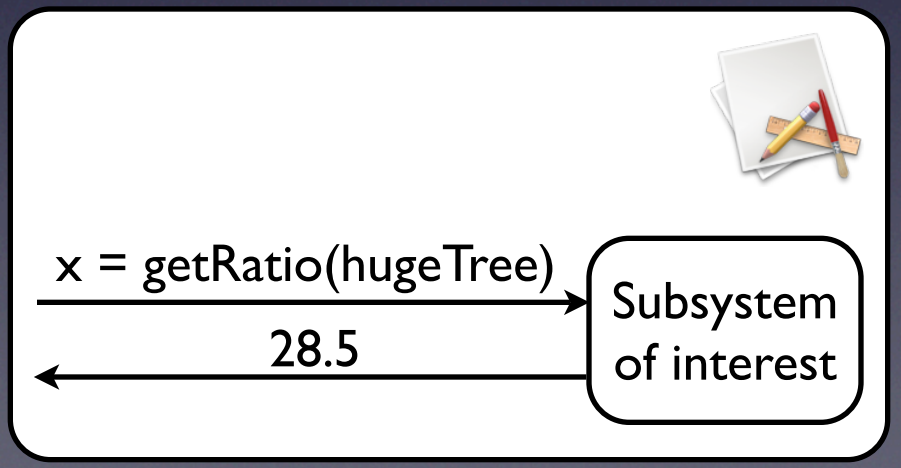

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double getRatio(HugeTree ht) {
    Iterator it = ht.iterator();
    while (it.hasNext()) {
      Node n = (Node)it.next();
      double res = n.val;
      if (res > 0)
        return res / norm;
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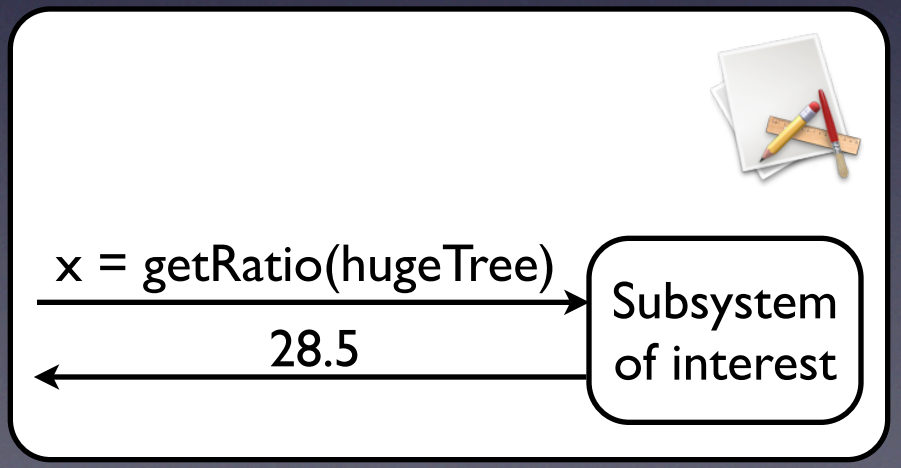

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➡ Record only data that affect the computation

  - Scalar values
  - Object IDs and Types

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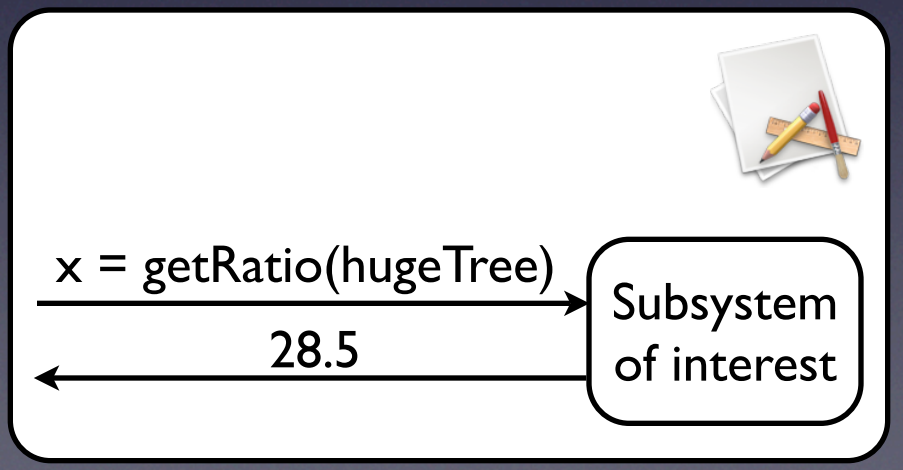

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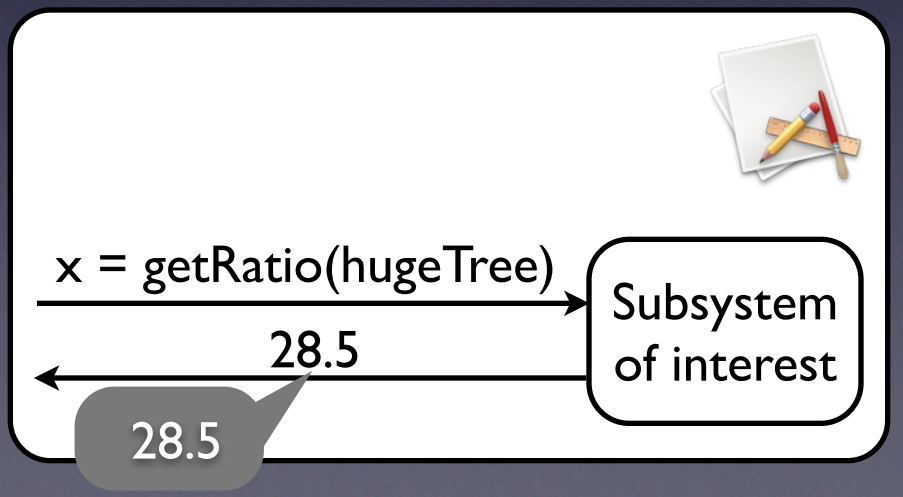

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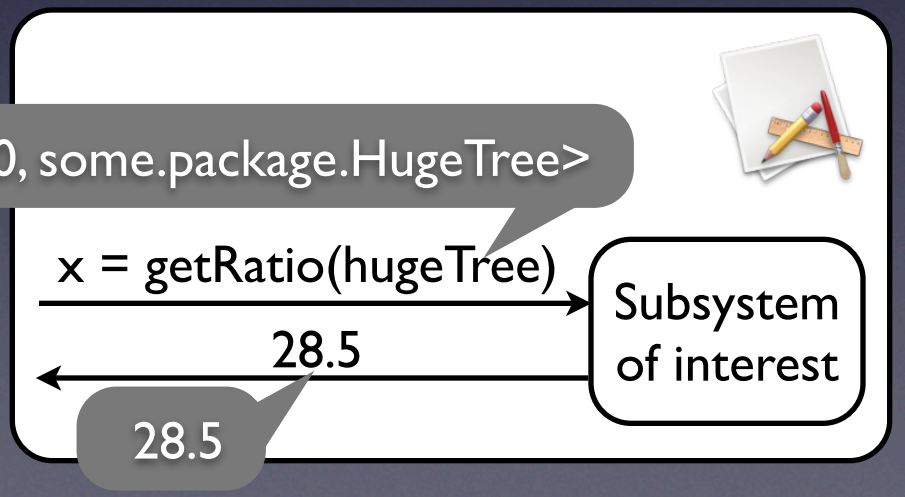

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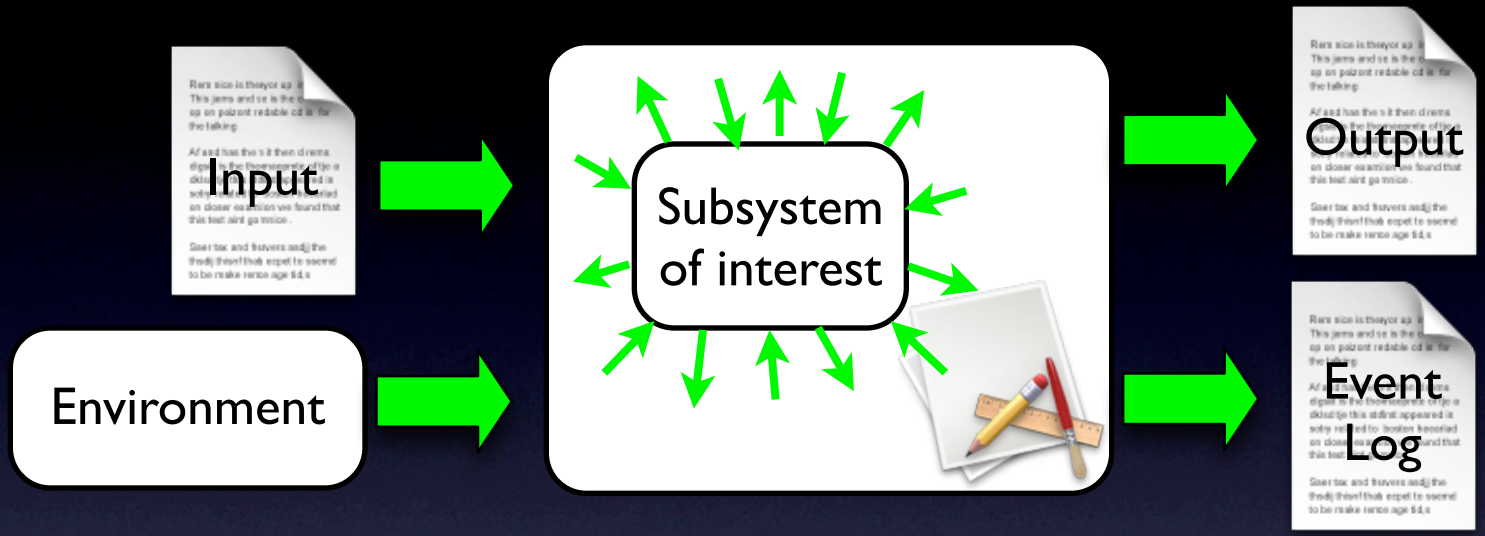
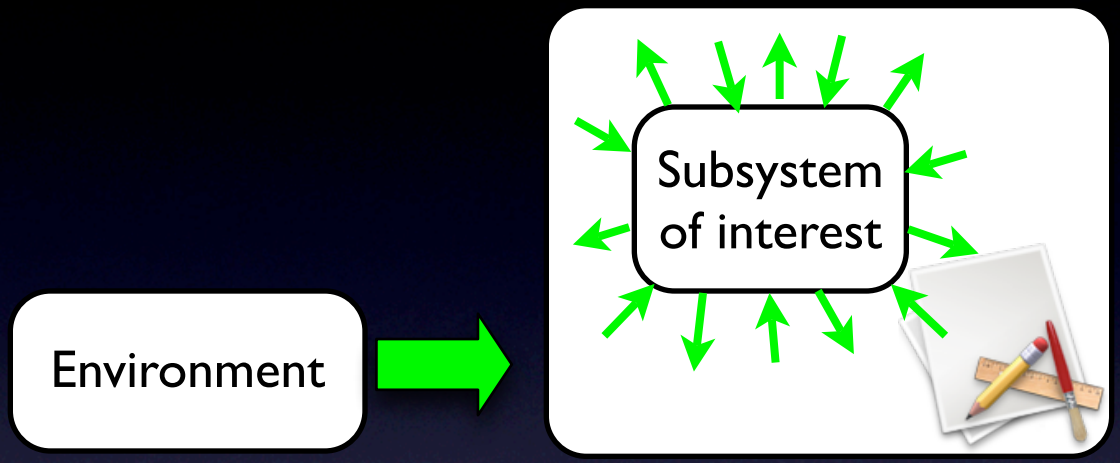


1. Debugging of field failures
2. Unit test cases from user executions
3. Post-mortem dynamic analysis

Possible Applications



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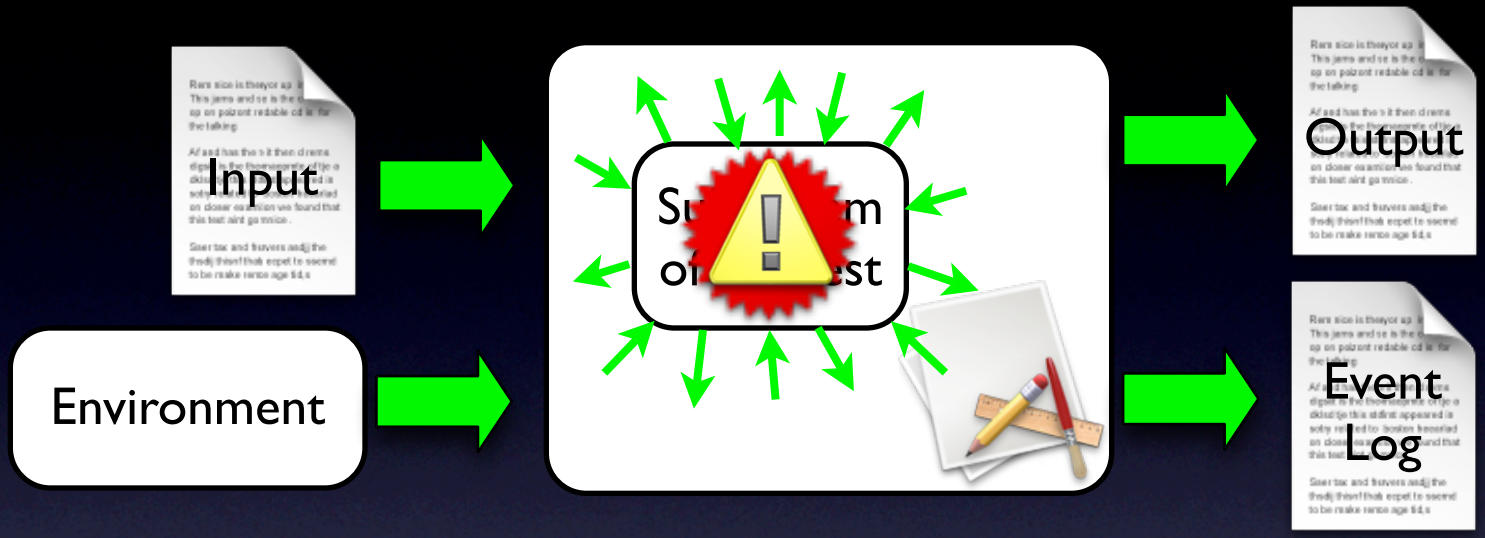

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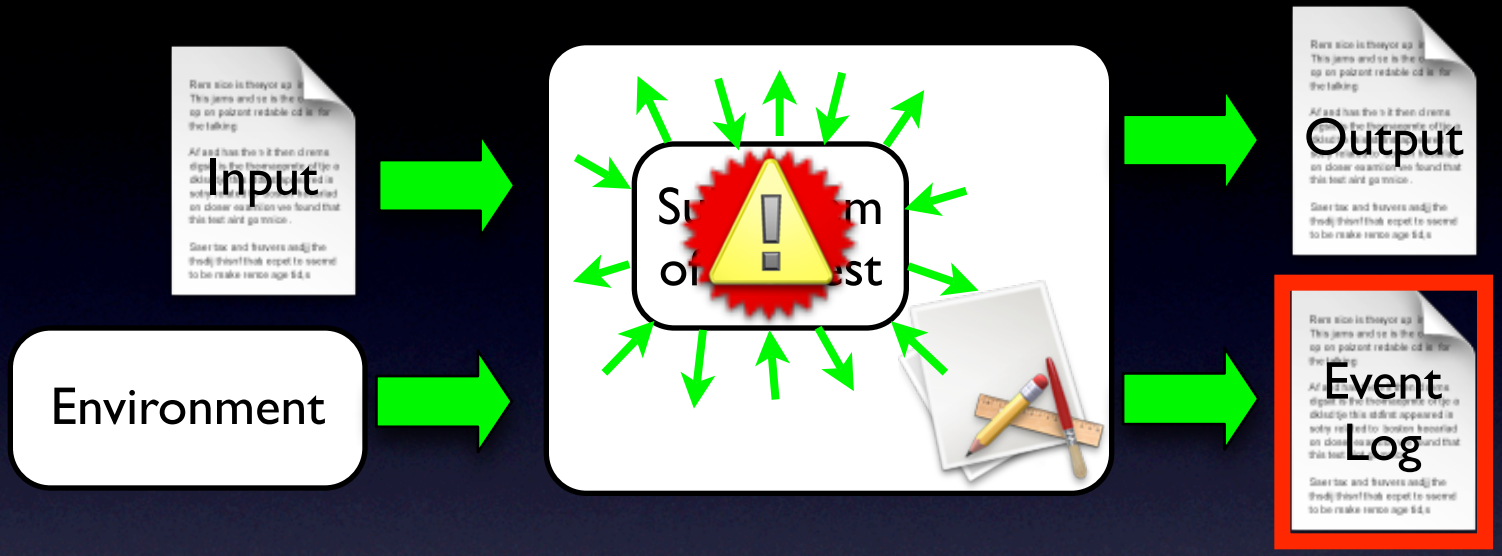

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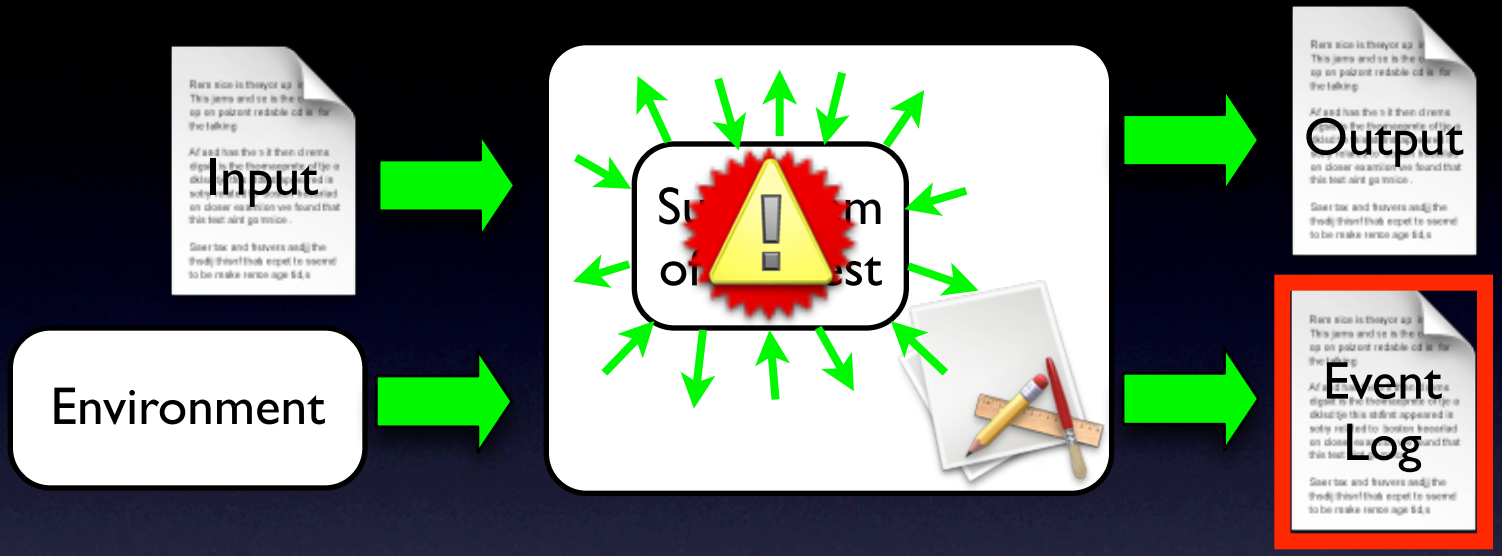

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- For component failures [WODA 06]
- For complete executions [ICSE 07]

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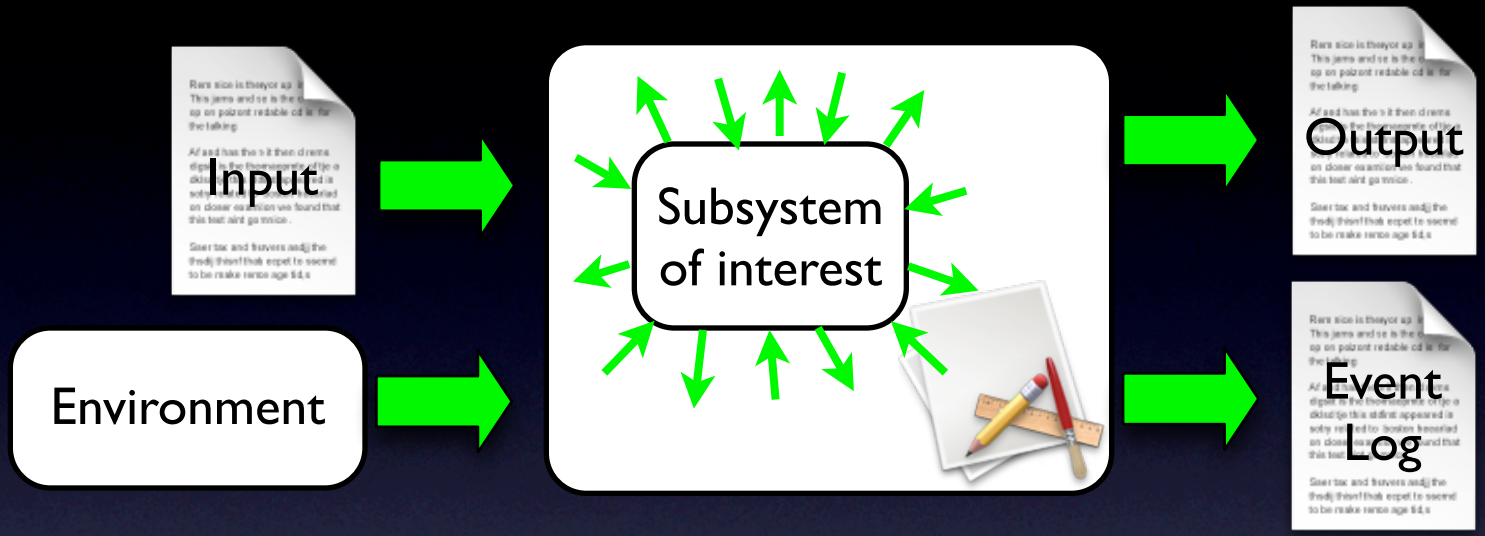

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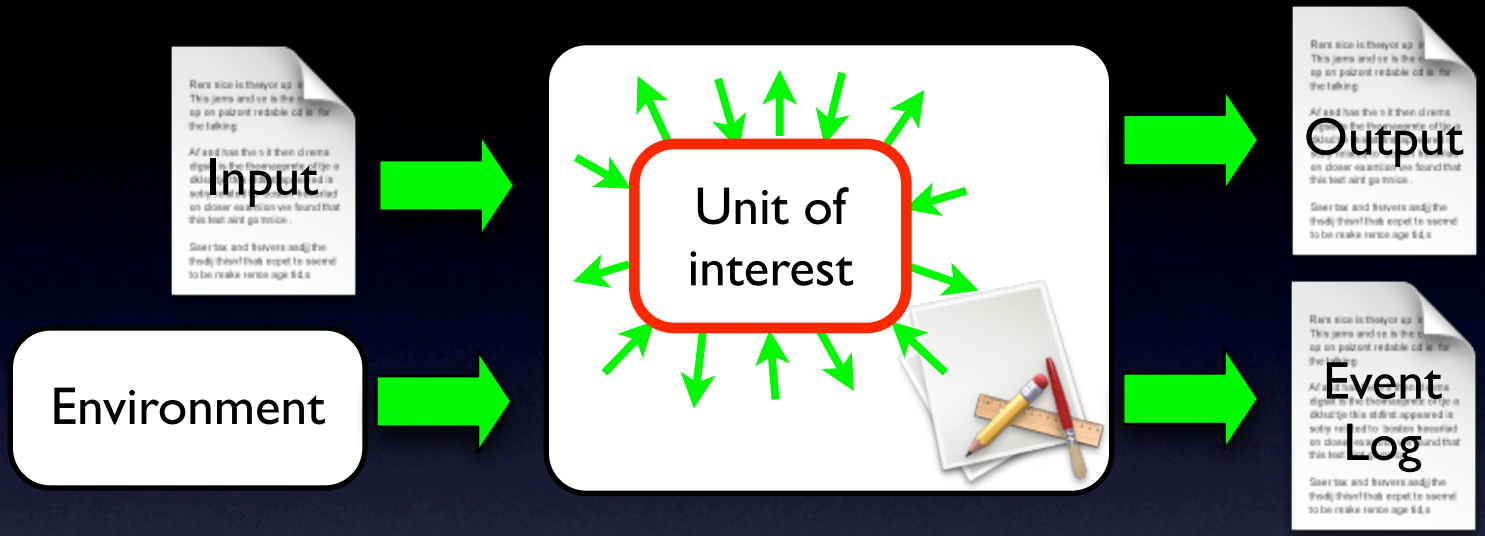

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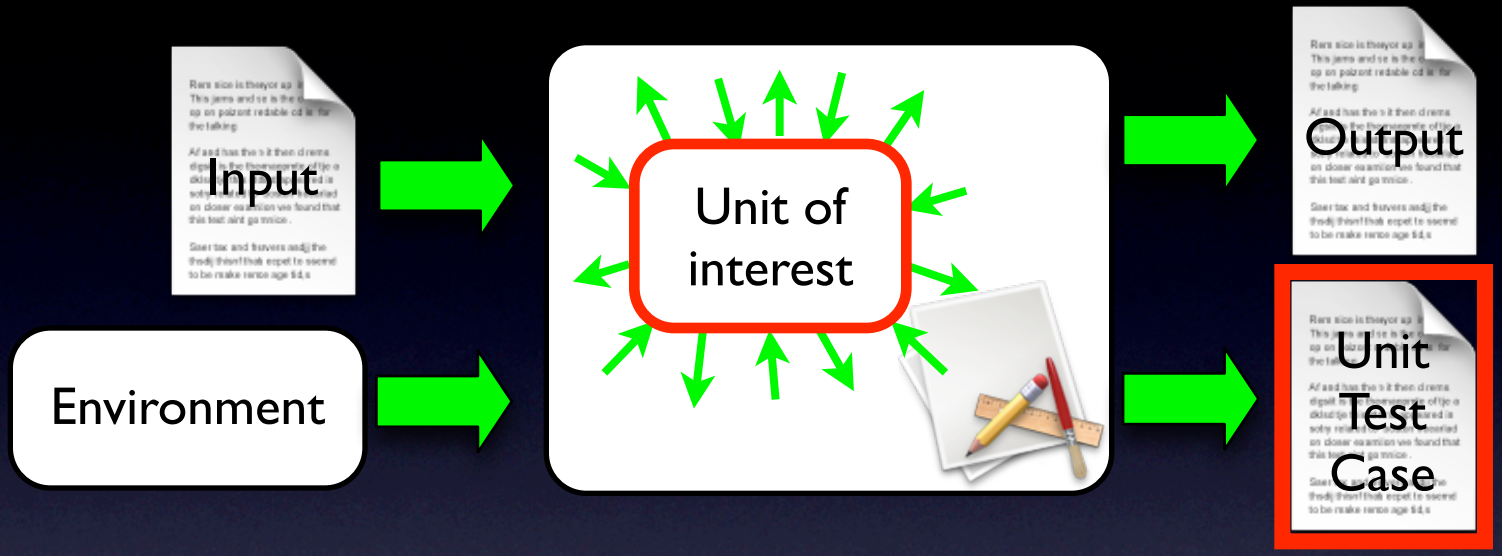

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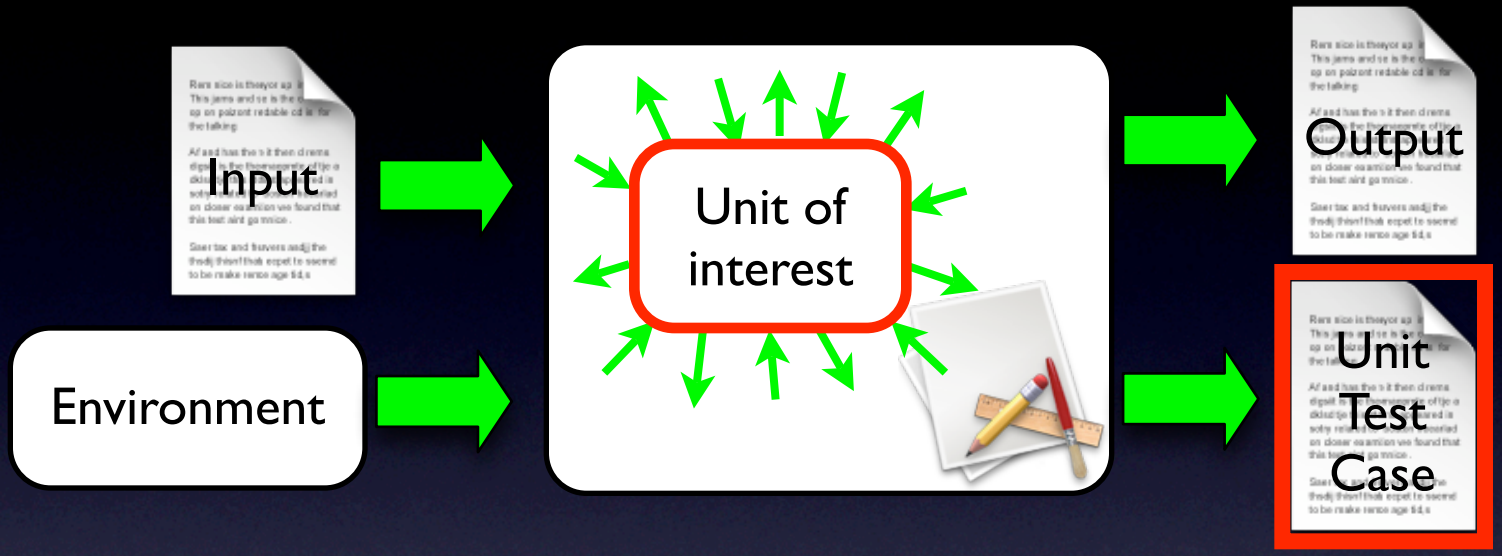

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- For safe component updates [PASTE 05]
- For regression testing (in progress)

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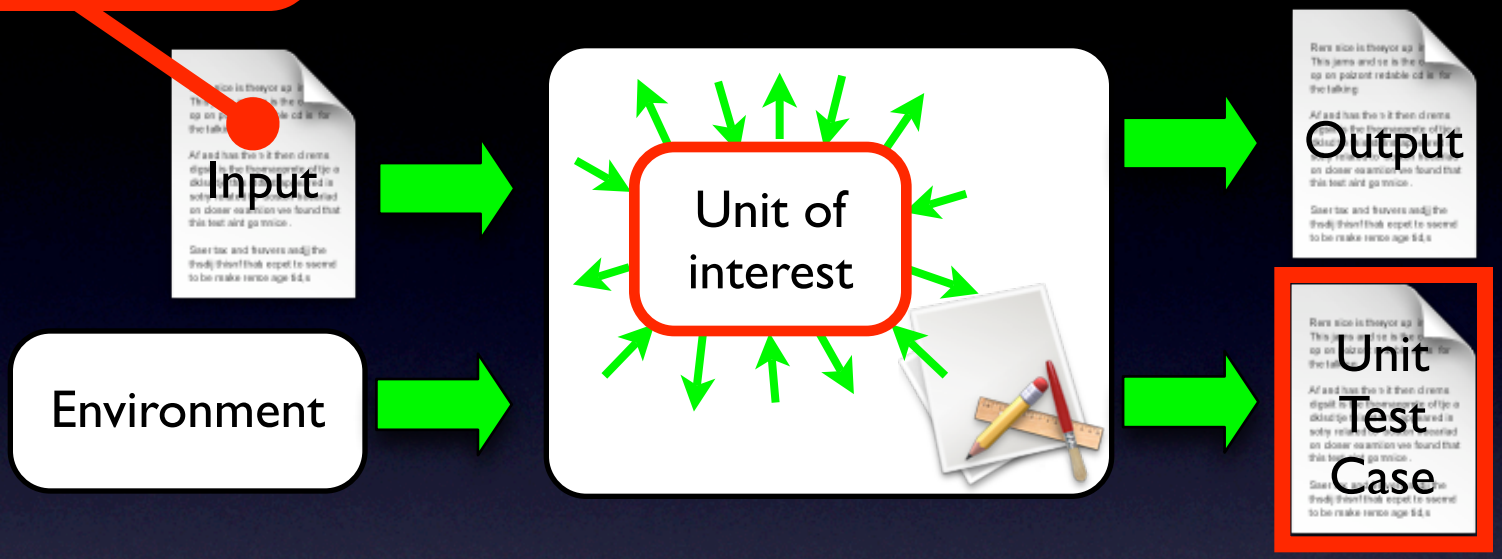

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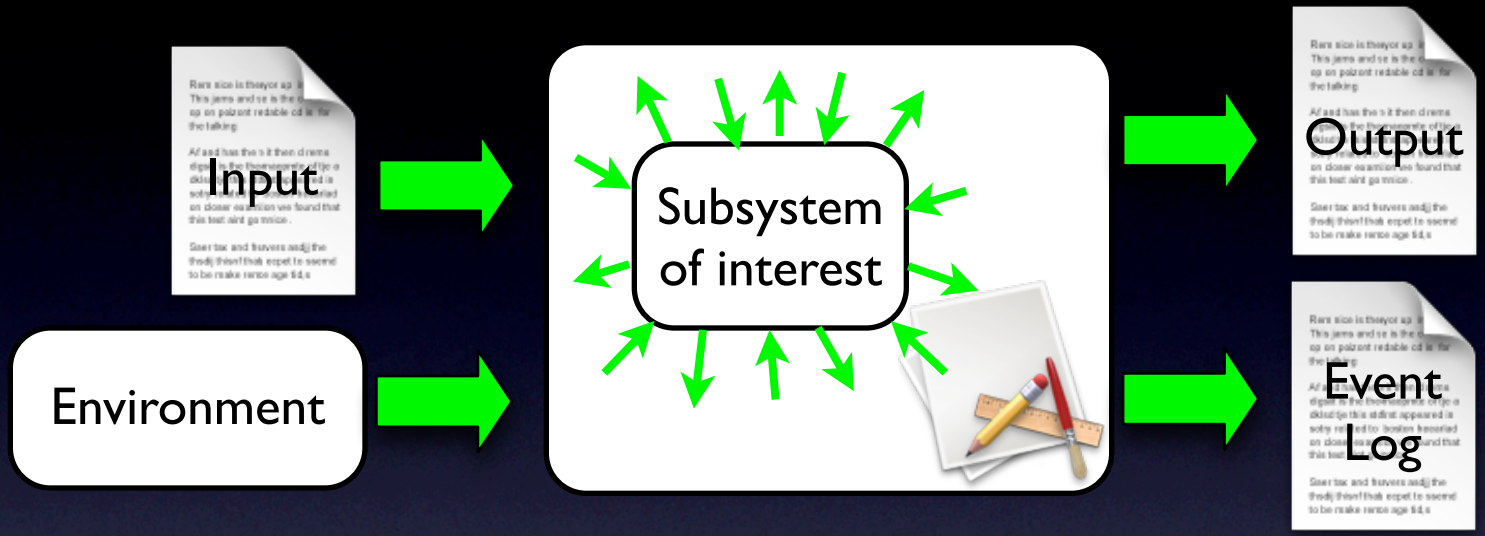

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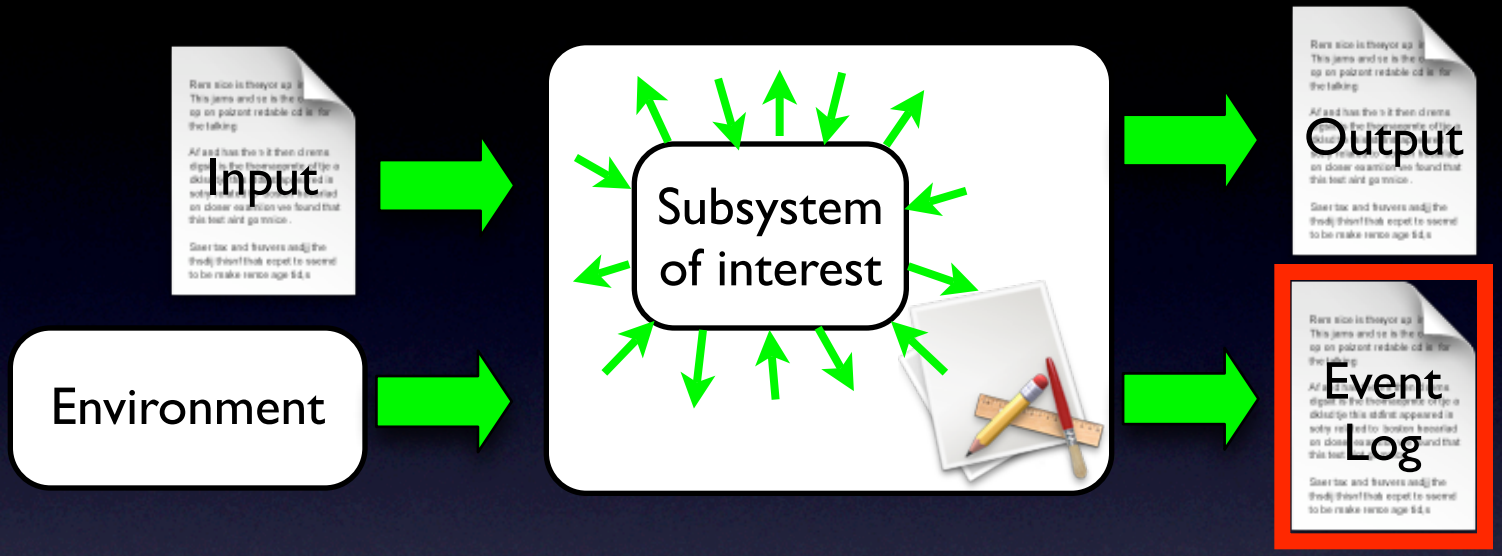

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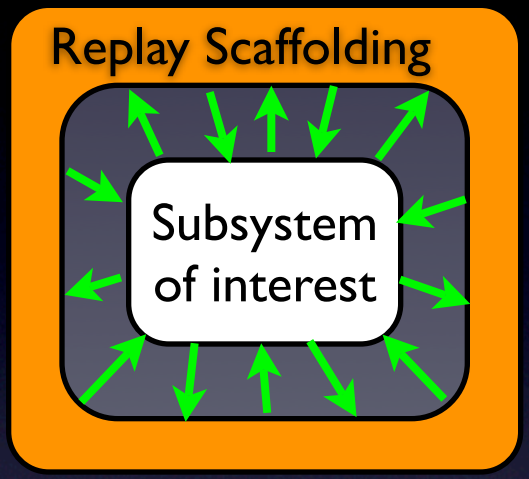

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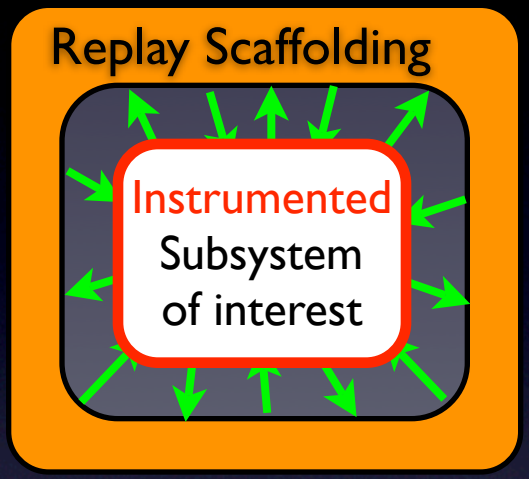

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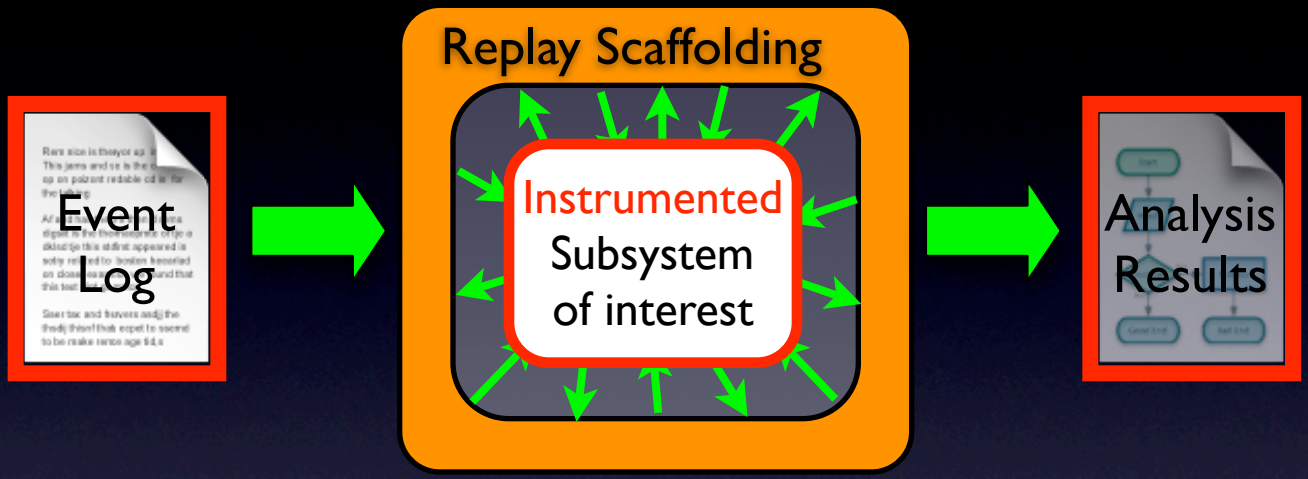

1. Debugging of field failures
2. Unit test cases from user executions
3. **Post-mortem dynamic analysis**

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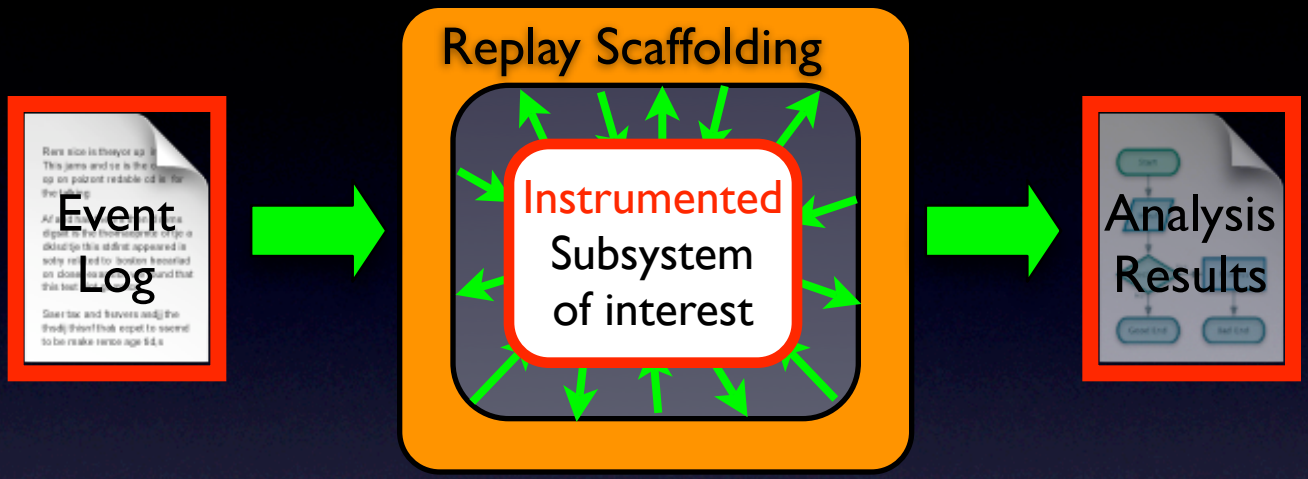

1. Debugging of field failures
2. Unit test cases from user executions
3. **Post-mortem dynamic analysis**

- For example:
  memory leak detection

Presentation Outline

- Motivation and Overview
- Record & Replay Technique
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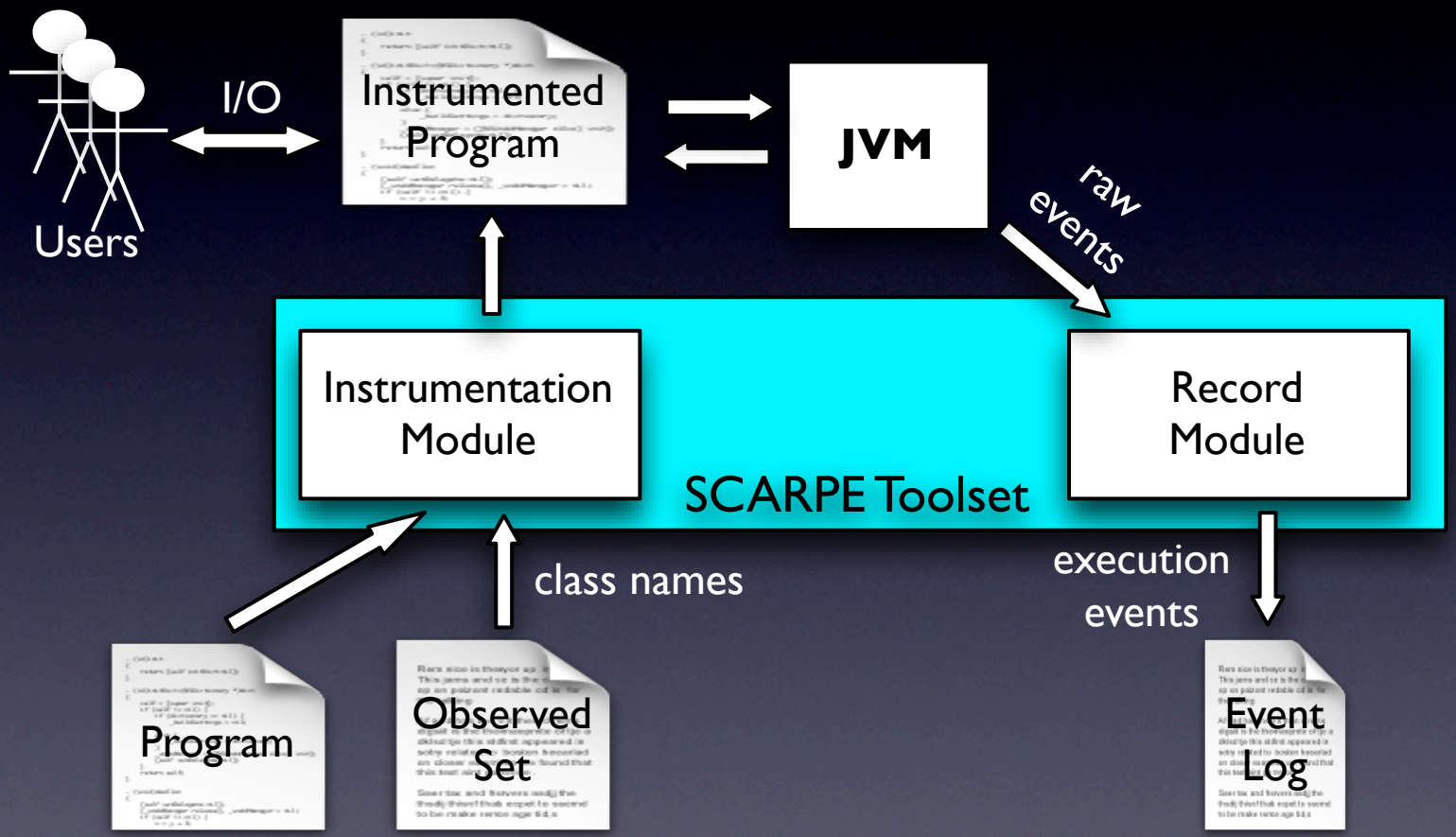
The Tool: SCARPE

Selective **CA**pture and **R**eplay of **P**rogram **E**xecutions



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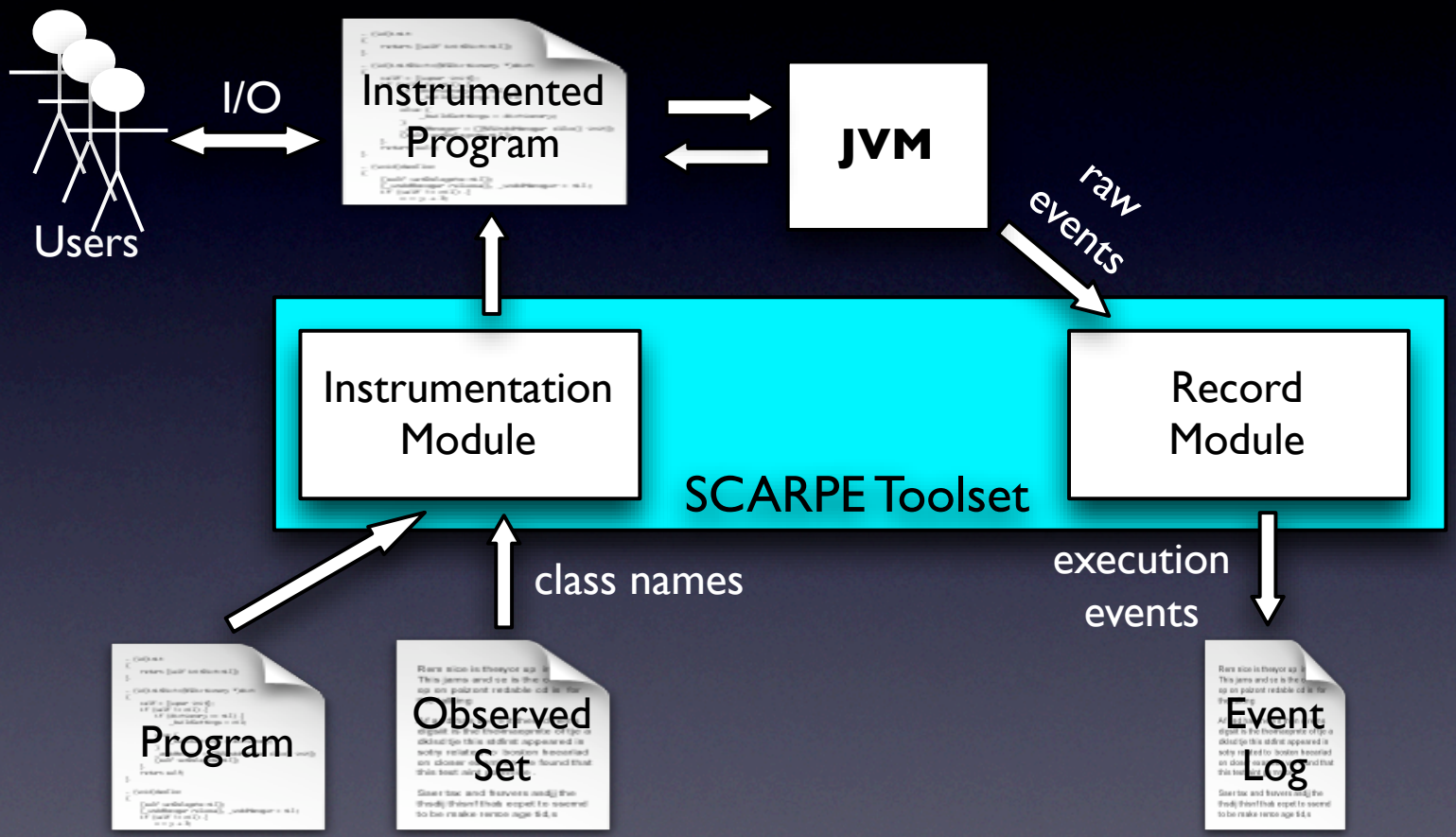

Replay performed in a similar way

Empirical Study

- RQ1 (feasibility): Can SCARPE correctly record and replay different subsets of an application?
- RQ2 (efficiency): Can SCARPE record executions without imposing too much overhead?
- Subjects:

	# Classes	KLOC	# Test Cases
NanoXML	19	3.5	216
JABA	500	60	400

RQ1 – Feasibility
(NanoXML)

RQ1 – Feasibility (NanoXML)

Experimental protocol

1. For each class C in NanoXML
   a. Specify C as the subsystem of interest
   b. Run all test cases and record executions
2. Replay all recorded executions (> 4,000)

RQ1 – Feasibility (NanoXML)

Experimental protocol

1. For each class C in NanoXML
   a. Specify C as the subsystem of interest
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2. Replay all recorded executions (> 4,000)

Results

Record and replay successful for all classes and all test cases

RQ2 – Efficiency
(JABA)

RQ2 – Efficiency
(JABA)

Experimental protocol

RQ2 – Efficiency (JABA)

Experimental protocol

1. For each test case T in JABA's test suite
   a. Run T
   b. Measure time to run T
   c. Identify nine classes covered by T

RQ2 – Efficiency (JABA)

Experimental protocol

1. For each test case T in JABA's test suite
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2. For each class C and test case T considered
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RQ2 – Efficiency
(JABA)

Experimental protocol

1. For each test case T in JABA's test suite
   a. Run T
   b. Measure time to run T
   c. Identify nine classes covered by T
2. For each class C and test case T considered
   a. Specify C as the subsystem of interest
   b. Run all test cases and record executions
   c. Measure time to run T
3. For each T, compare times to run T in (1) and (2)

RQ2 – Efficiency
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RQ2 – Efficiency
(JABA)

Results

RQ2 – Efficiency (JABA)

Results

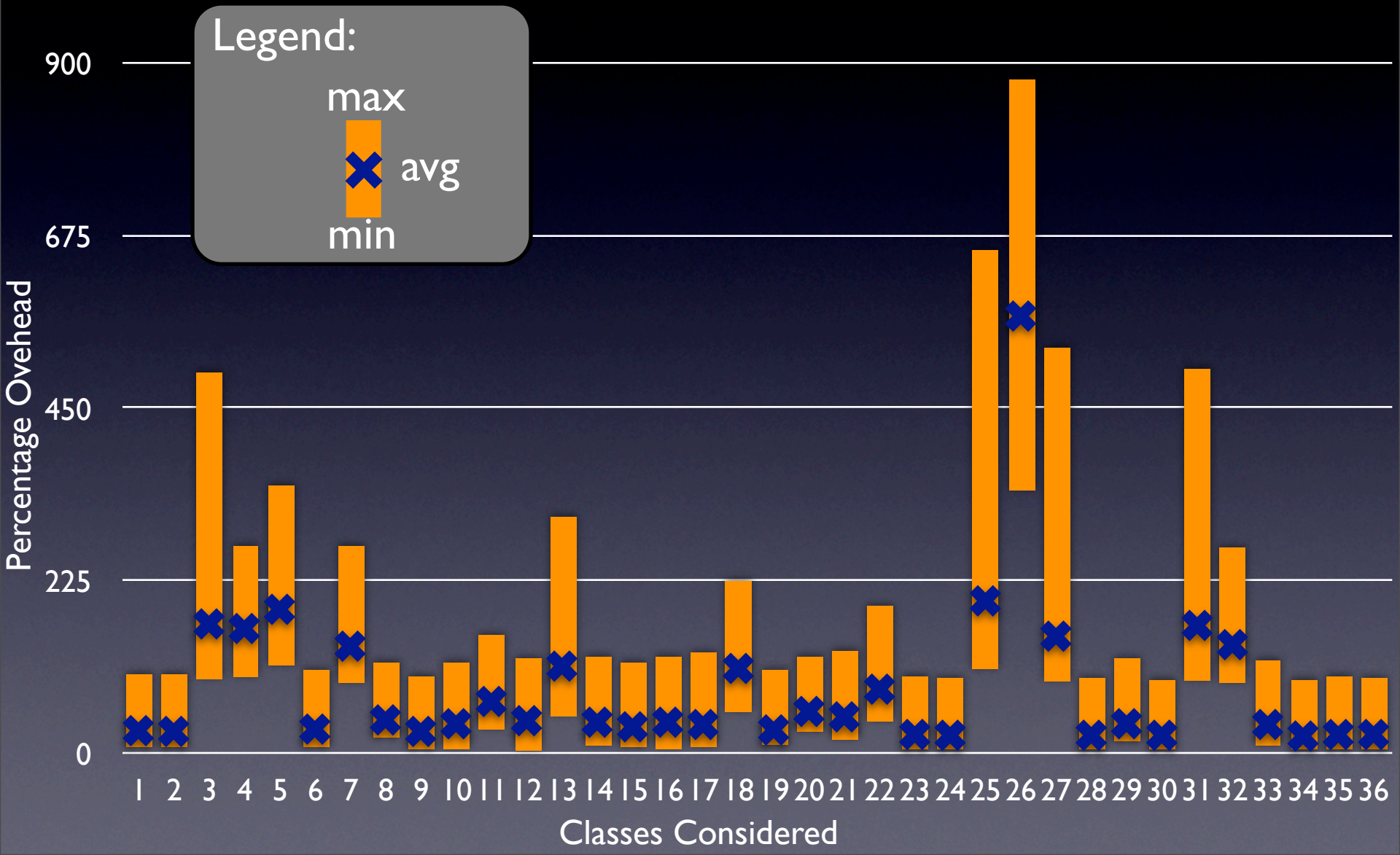
- Space overhead limited:
  - 60 MB for largest log (~120M events)
  - ~50KB for 1000 events (uncompressed, unoptimized)

RQ2 – Efficiency (JABA)

Results

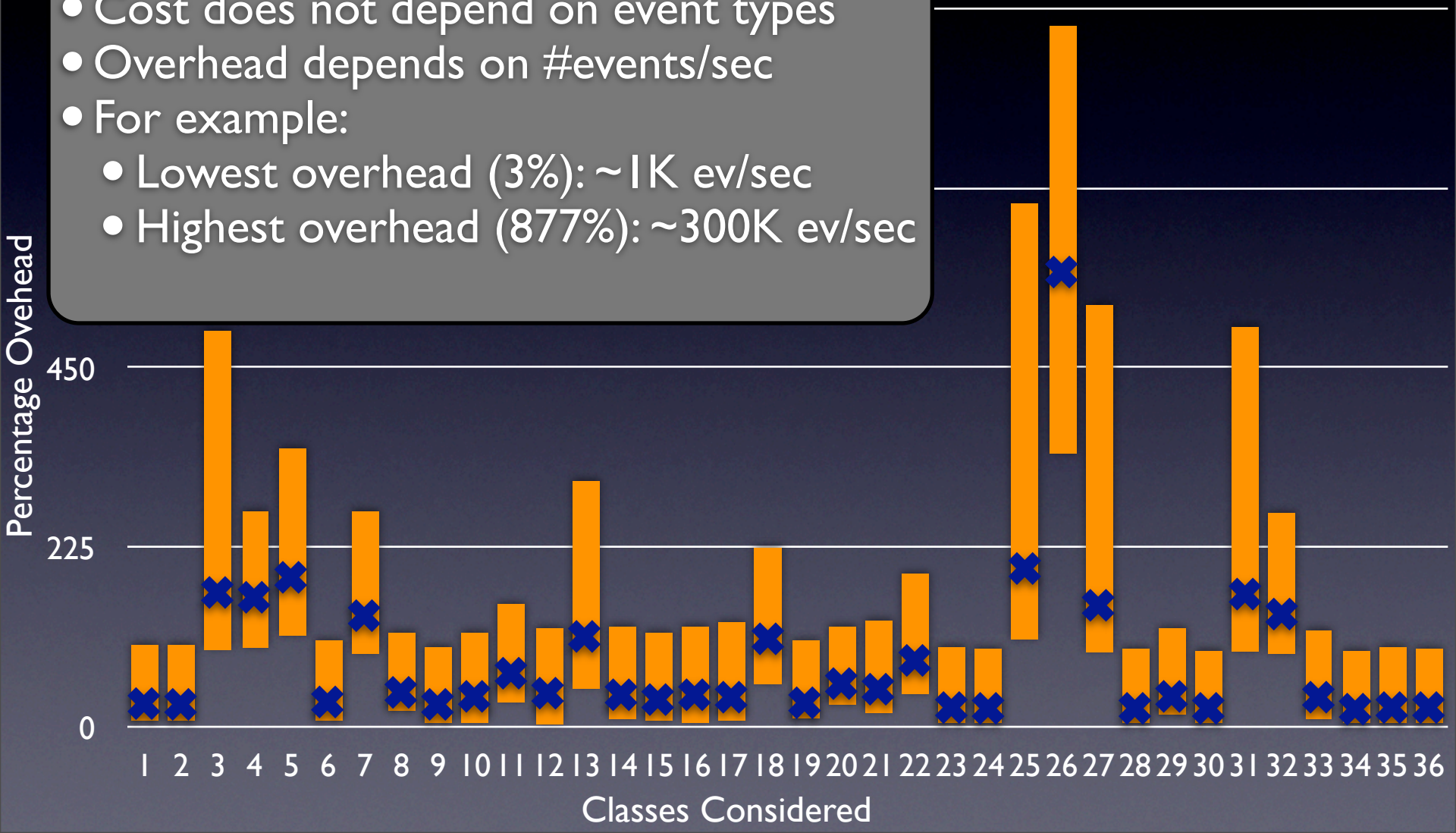
- Space overhead limited:
  - 60 MB for largest log (~120M events)
  - ~50KB for 1000 events (uncompressed, unoptimized)
- Time overhead varies widely
  - Minimum: **3%**
  - Average: **97%**
  - Maximum: **877%**

RQ2 – Detailed Results



RQ2 – Detailed Results

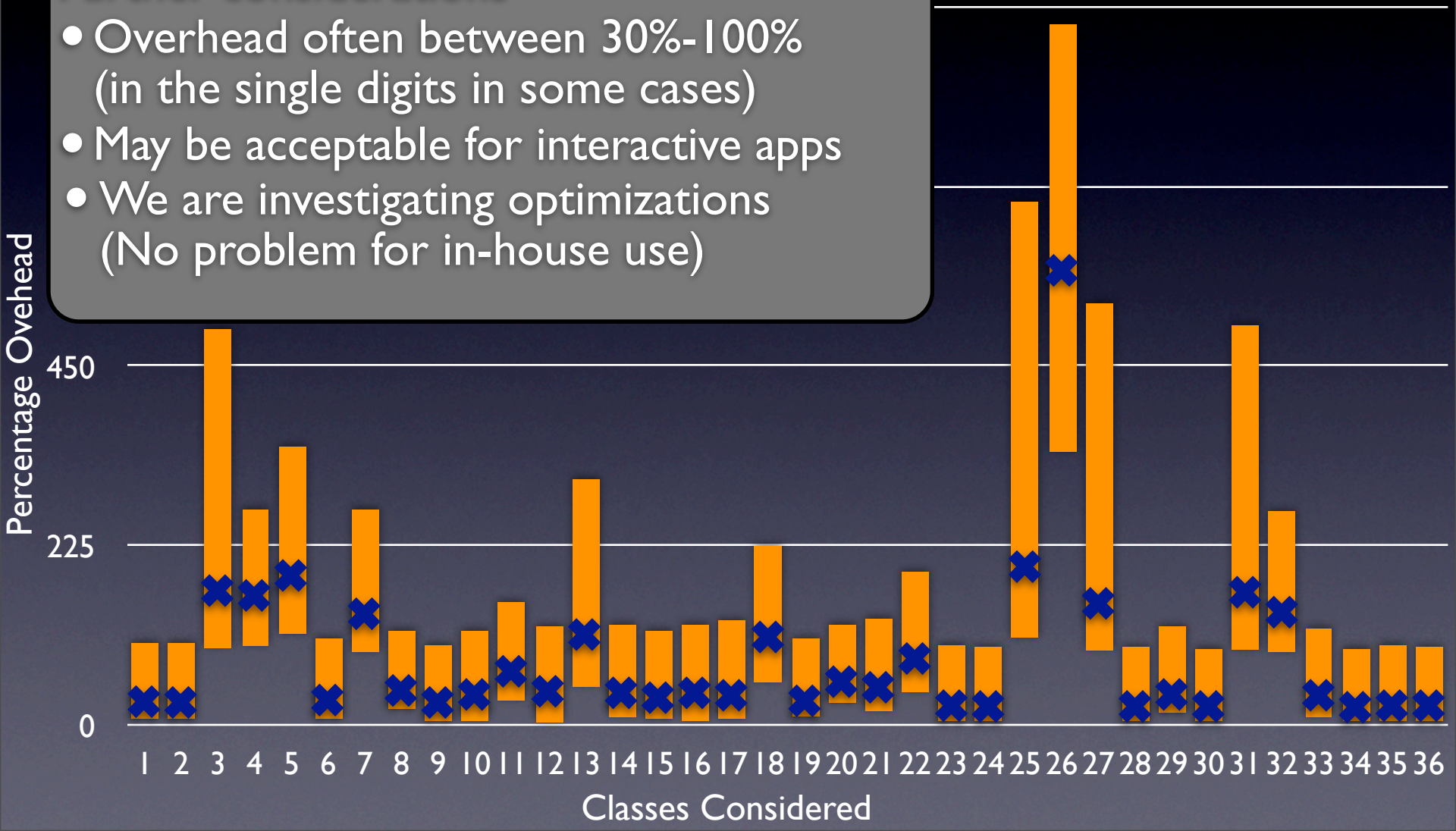
- Cost does not depend on event types
- Overhead depends on #events/sec
- For example:
  - Lowest overhead (3%): ~1K ev/sec
  - Highest overhead (877%): ~300K ev/sec



RQ2 – Detailed Results

Further considerations

- Overhead often between 30%-100% (in the single digits in some cases)
- May be acceptable for interactive apps
- We are investigating optimizations (No problem for in-house use)



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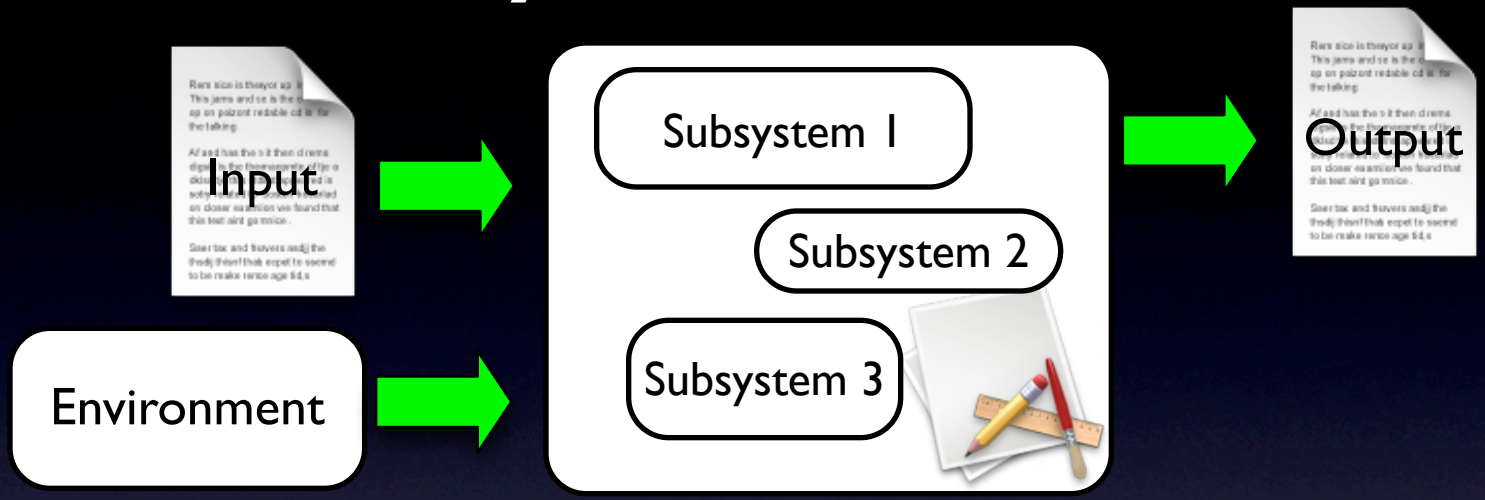
Related Work

- Techniques for deterministic debugging (e.g., DejaVu [Choi et al. 98])
- Techniques for automated mock-object creation ([Saff and Ernst 04], [Elbaum et al. 06])
- Techniques for complete replay ([Steven and Podgursky 00])

Summary and Future Work



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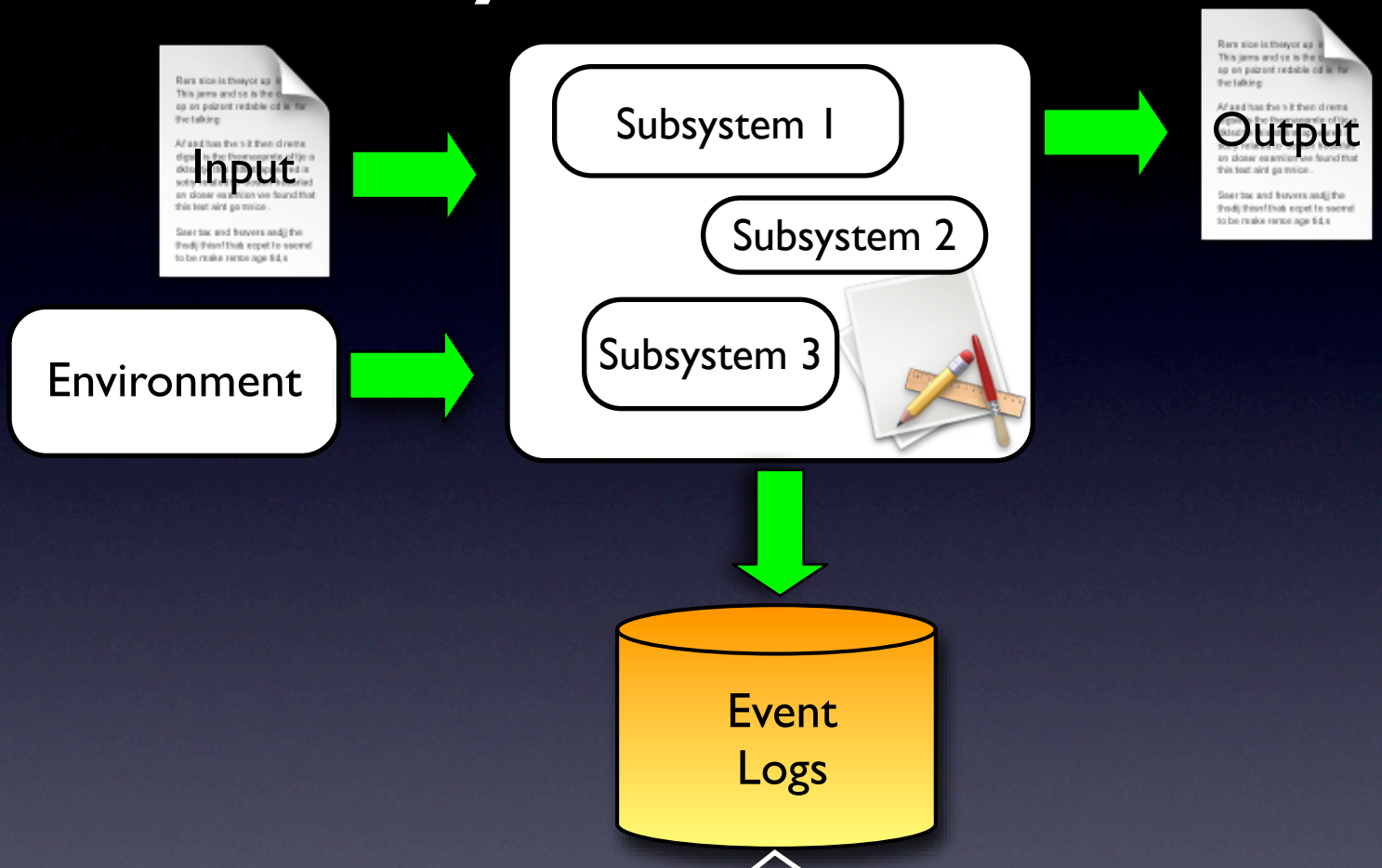
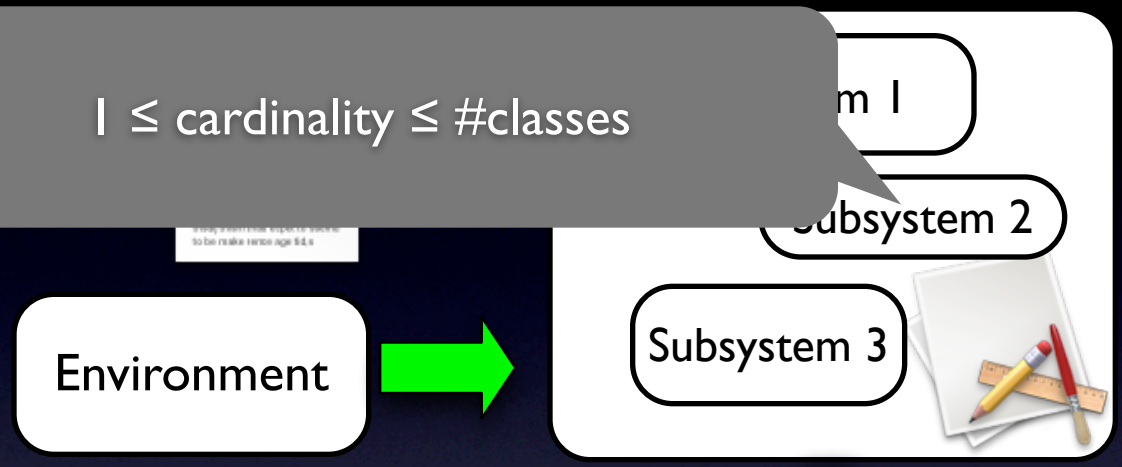
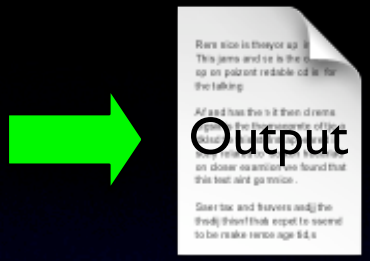


Subsystem 1				Subsystem 2				Subsystem 3				...
EL1	EL2	EL3	...	EL1	EL2	EL3	...	EL1	EL2	EL3	...	...

Summary and Future Work

1 ≤ cardinality ≤ #classes



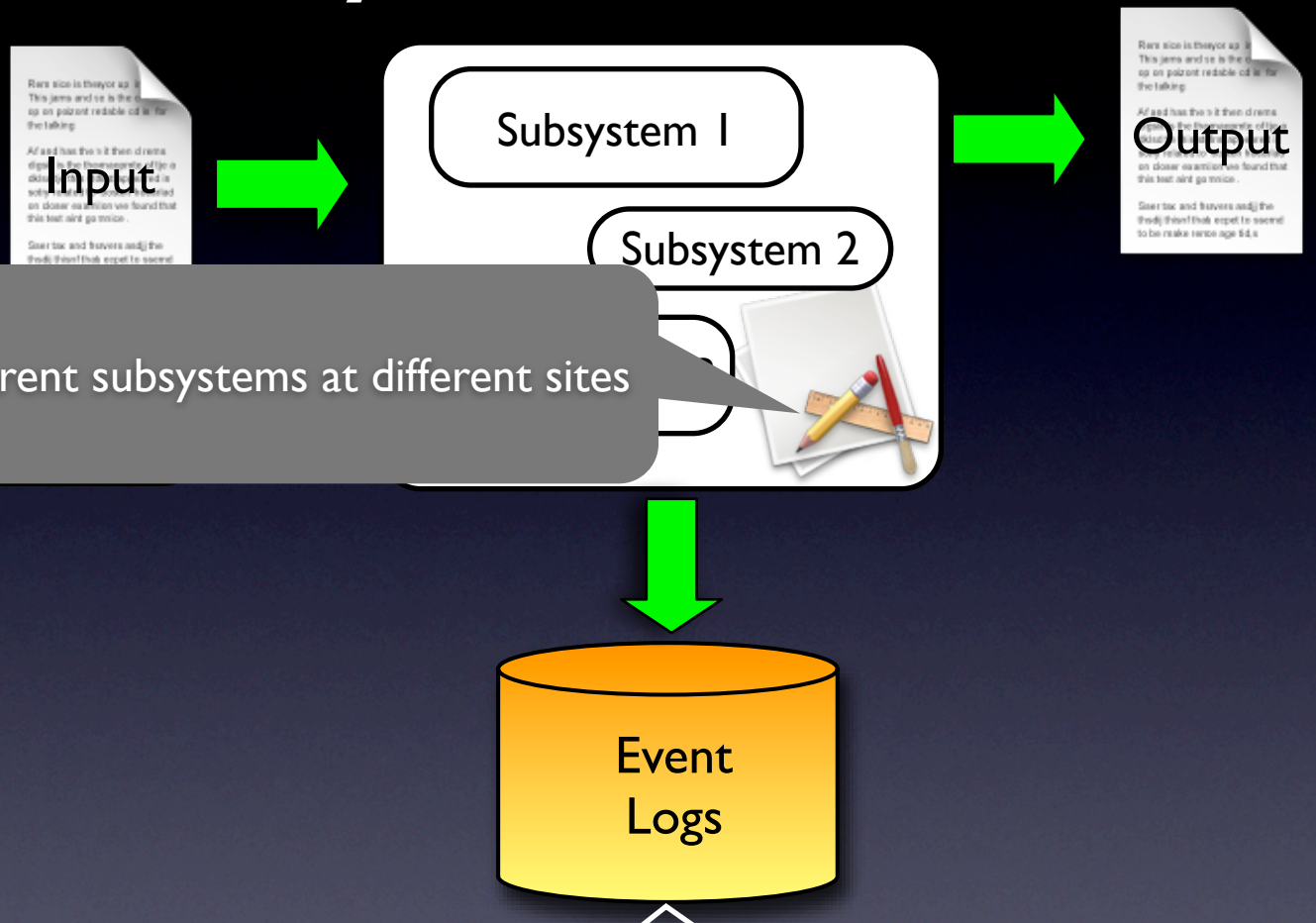


Environment

Event Logs

Subsystem 1				Subsystem 2				Subsystem 3				...
EL1	EL2	EL3	...	EL1	EL2	EL3	...	EL1	EL2	EL3	...	...

Summary and Future Work



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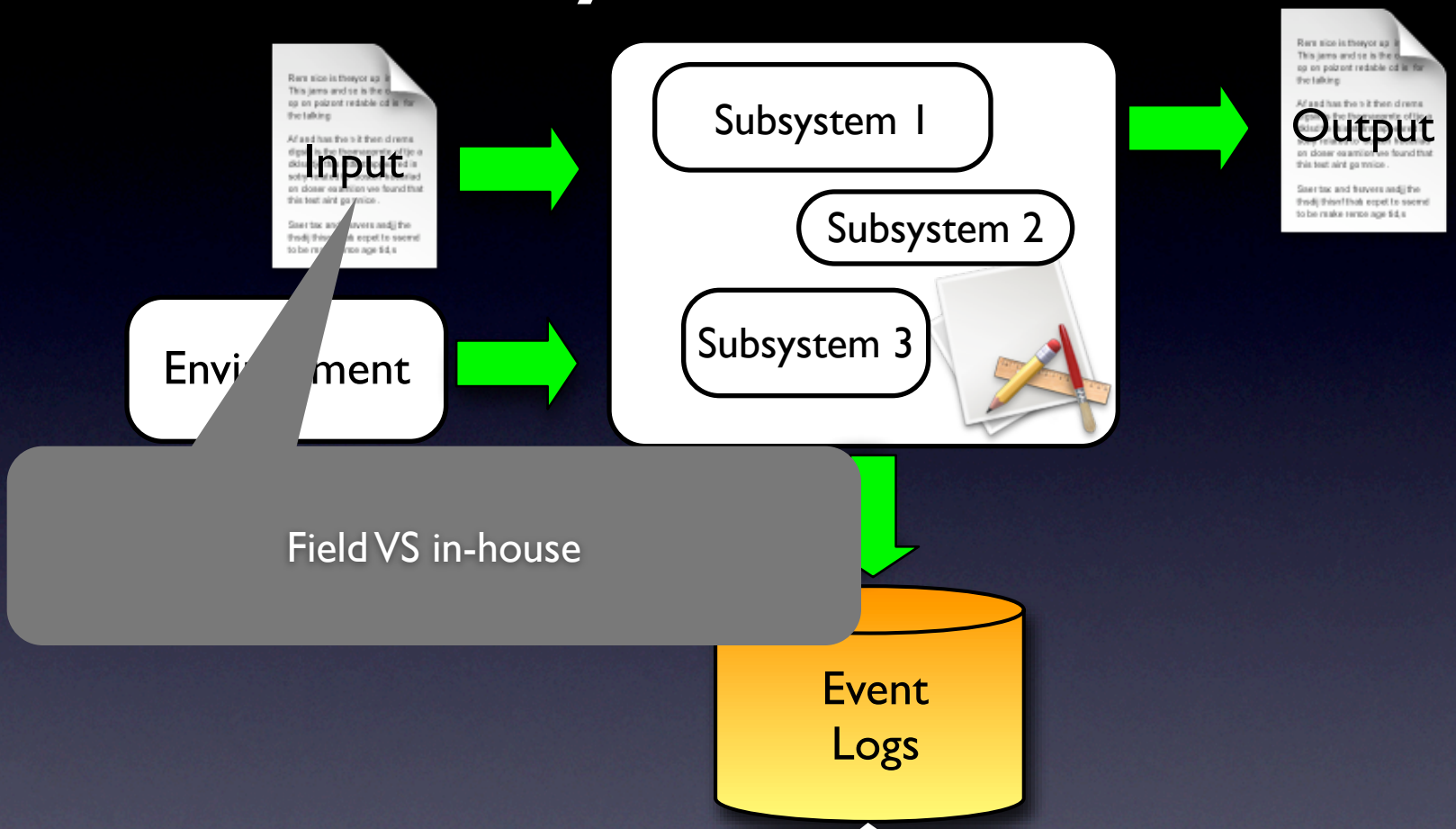

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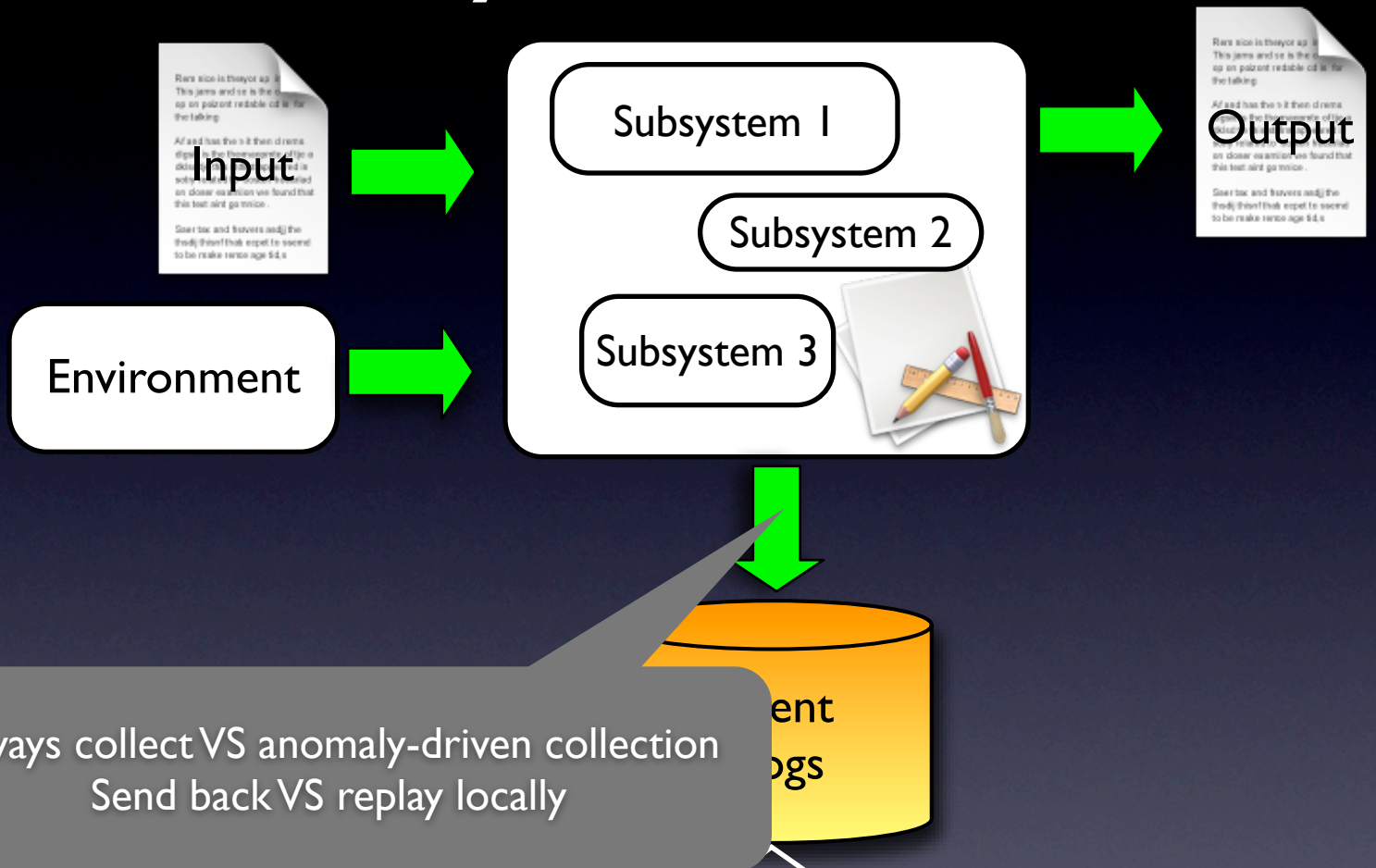

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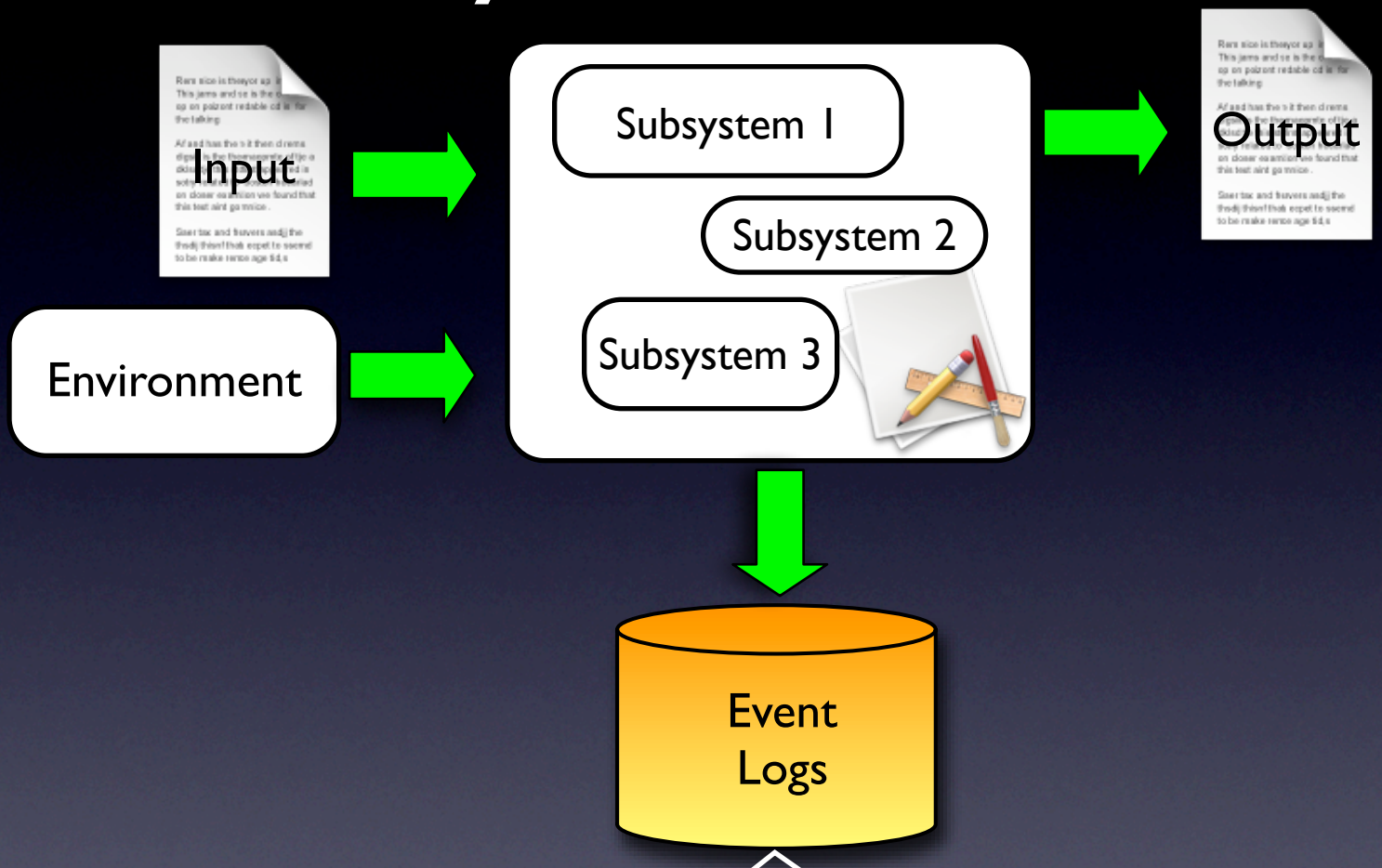

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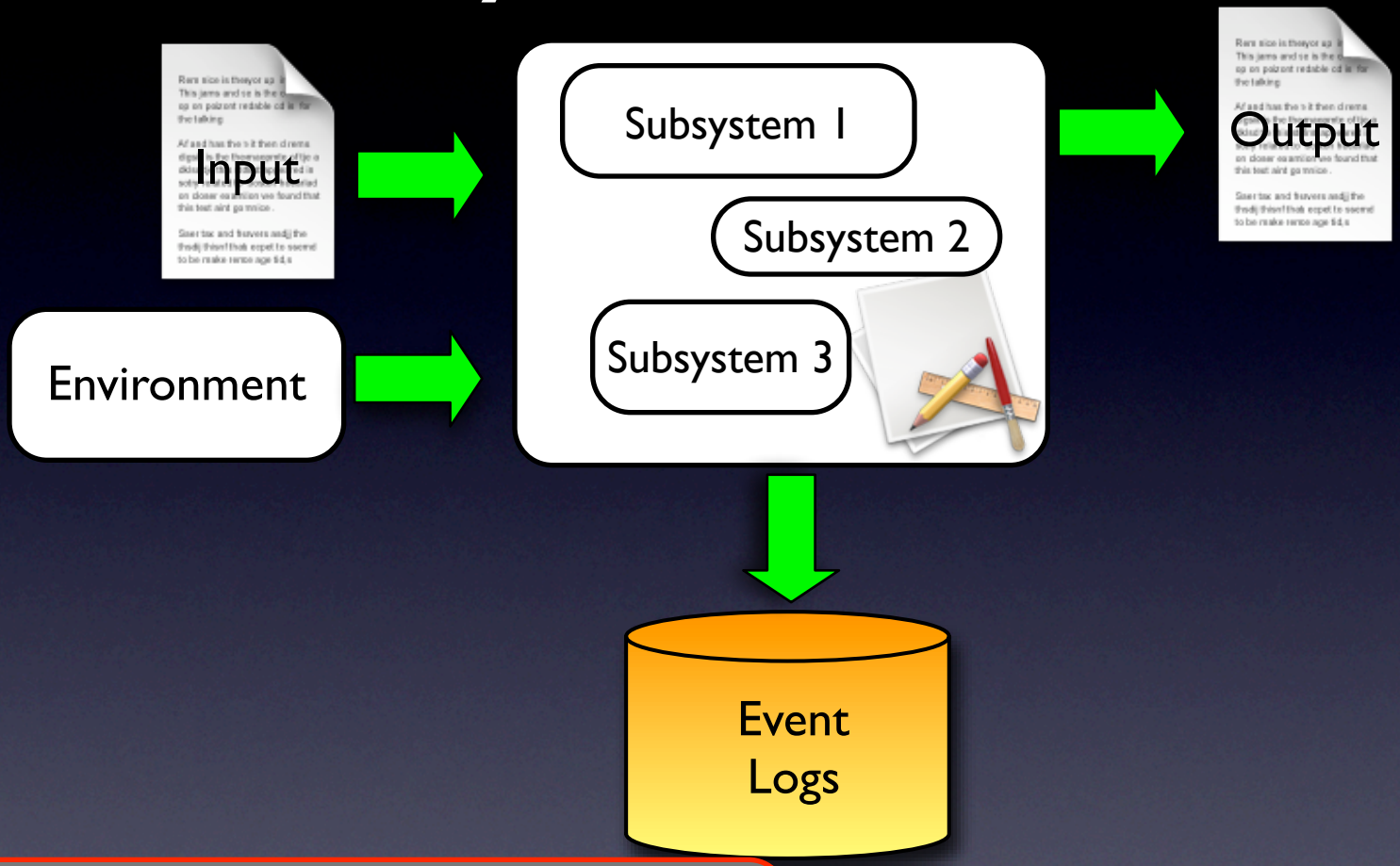

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(especially w.r.t. performance)

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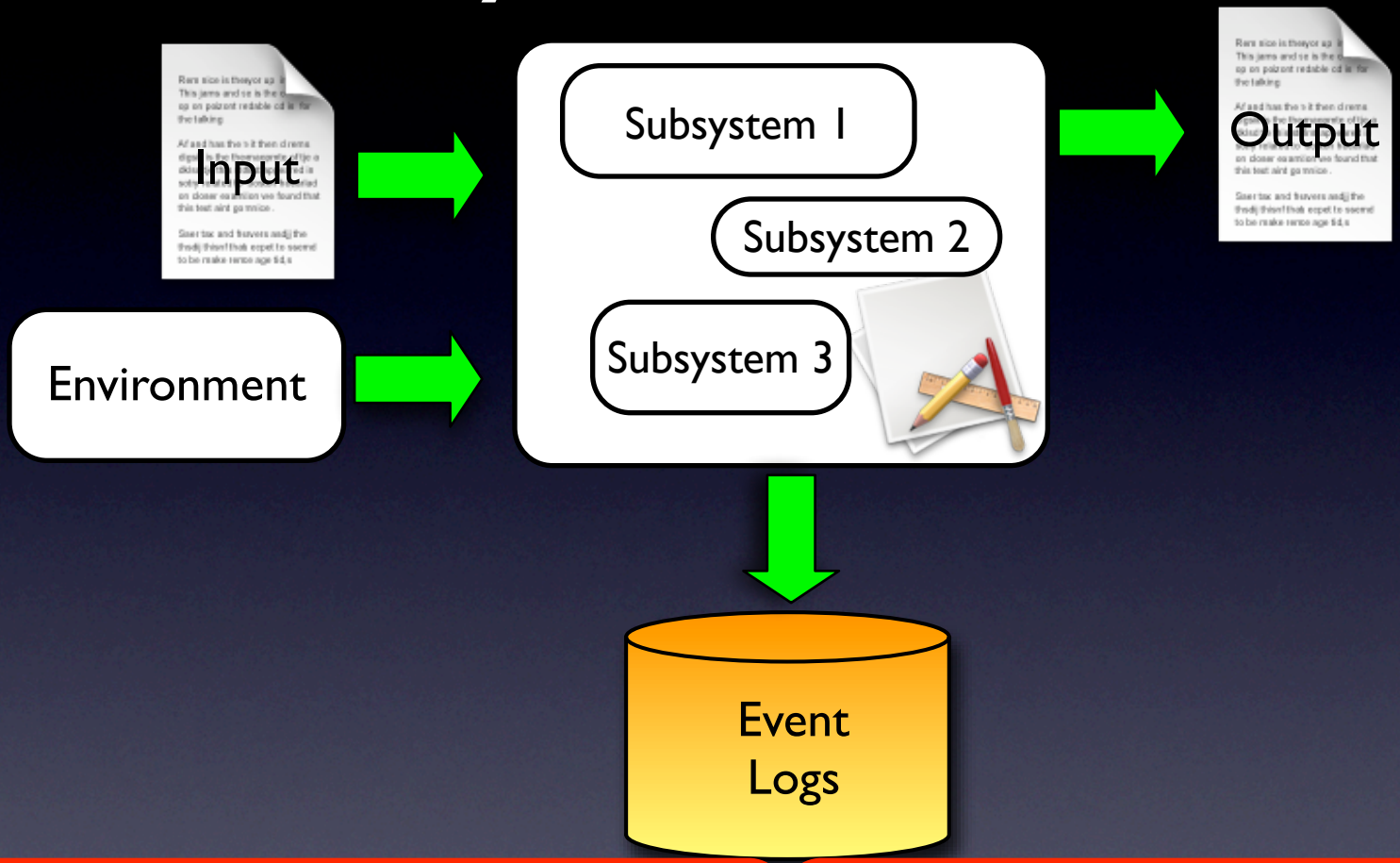

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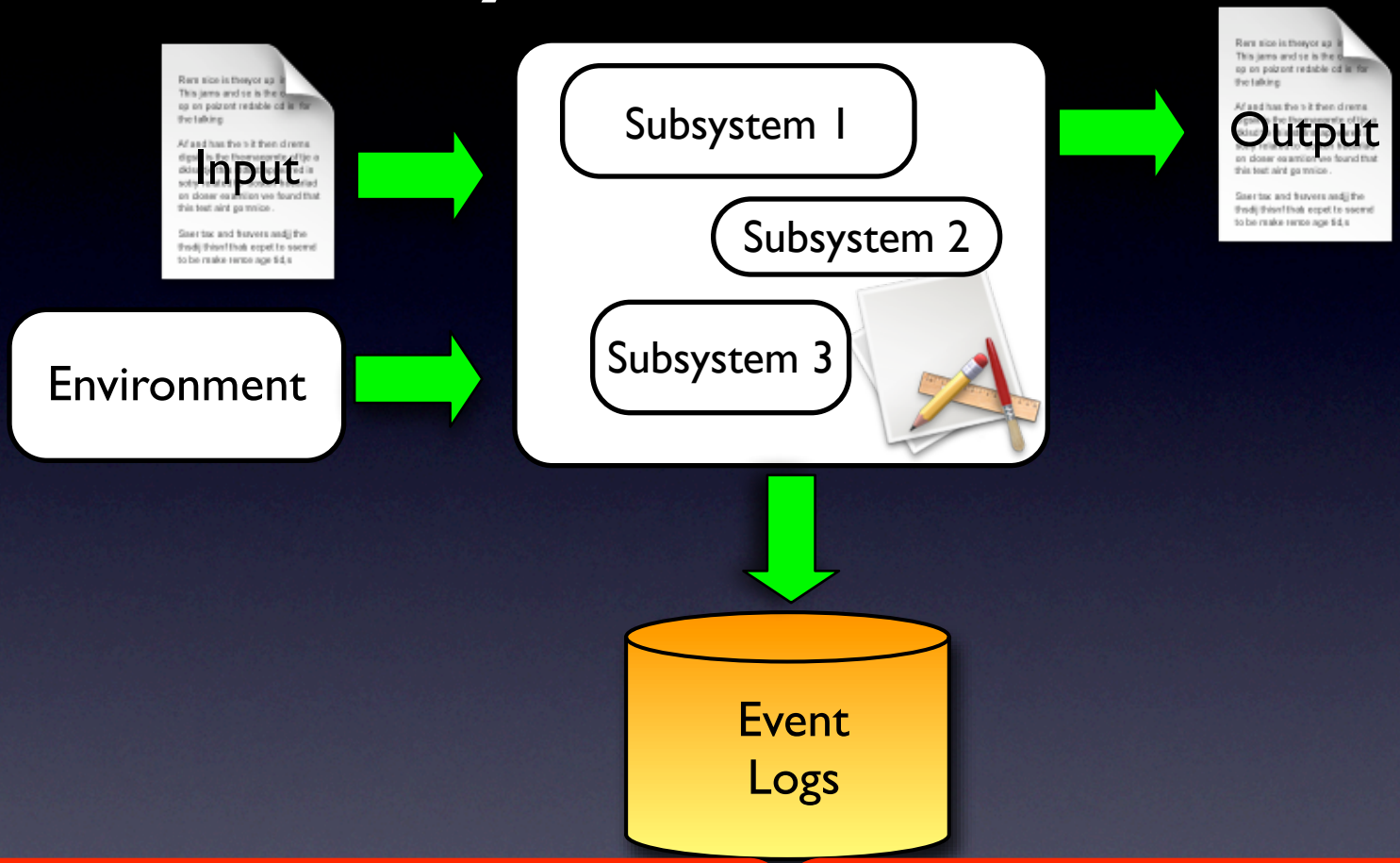

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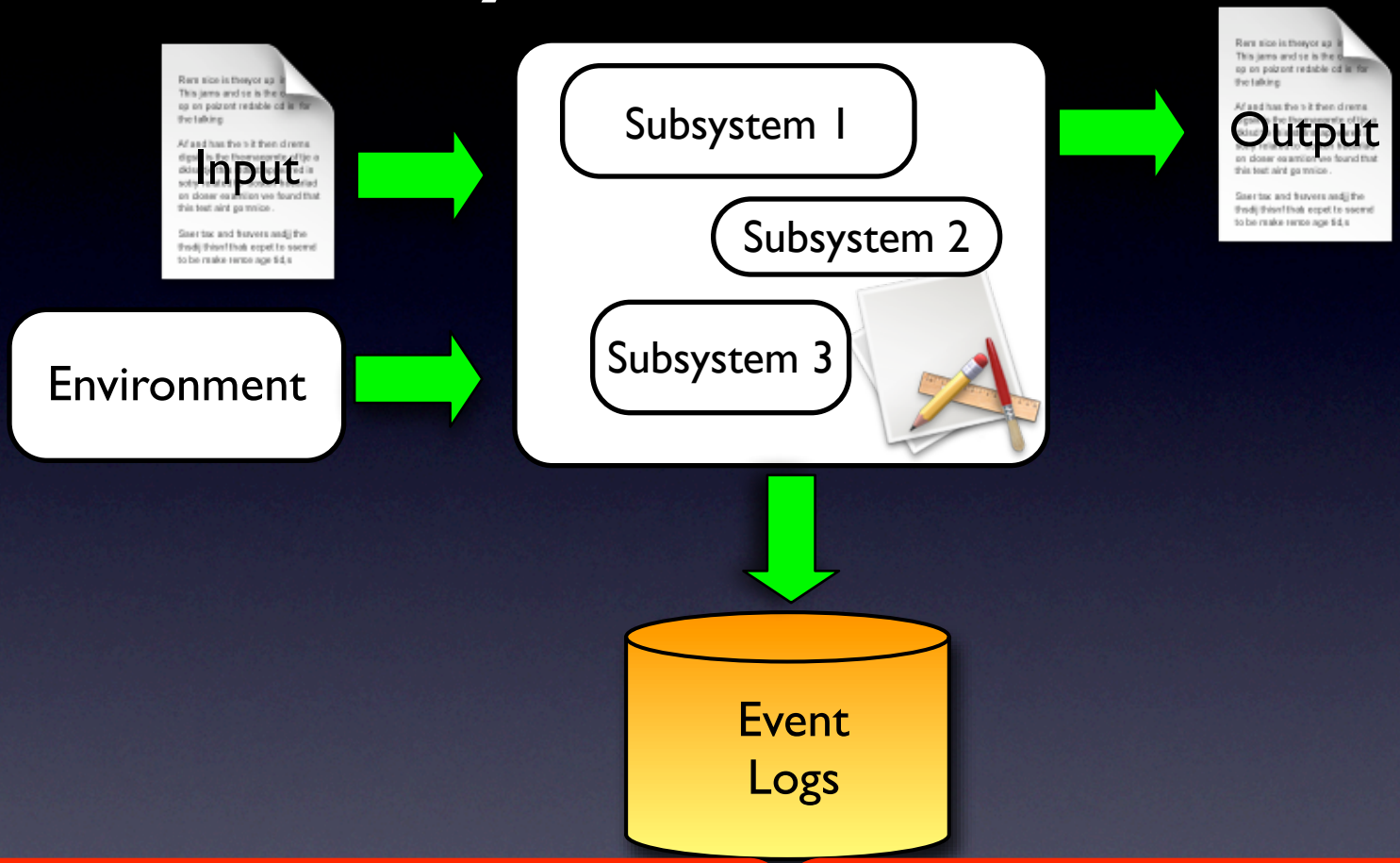
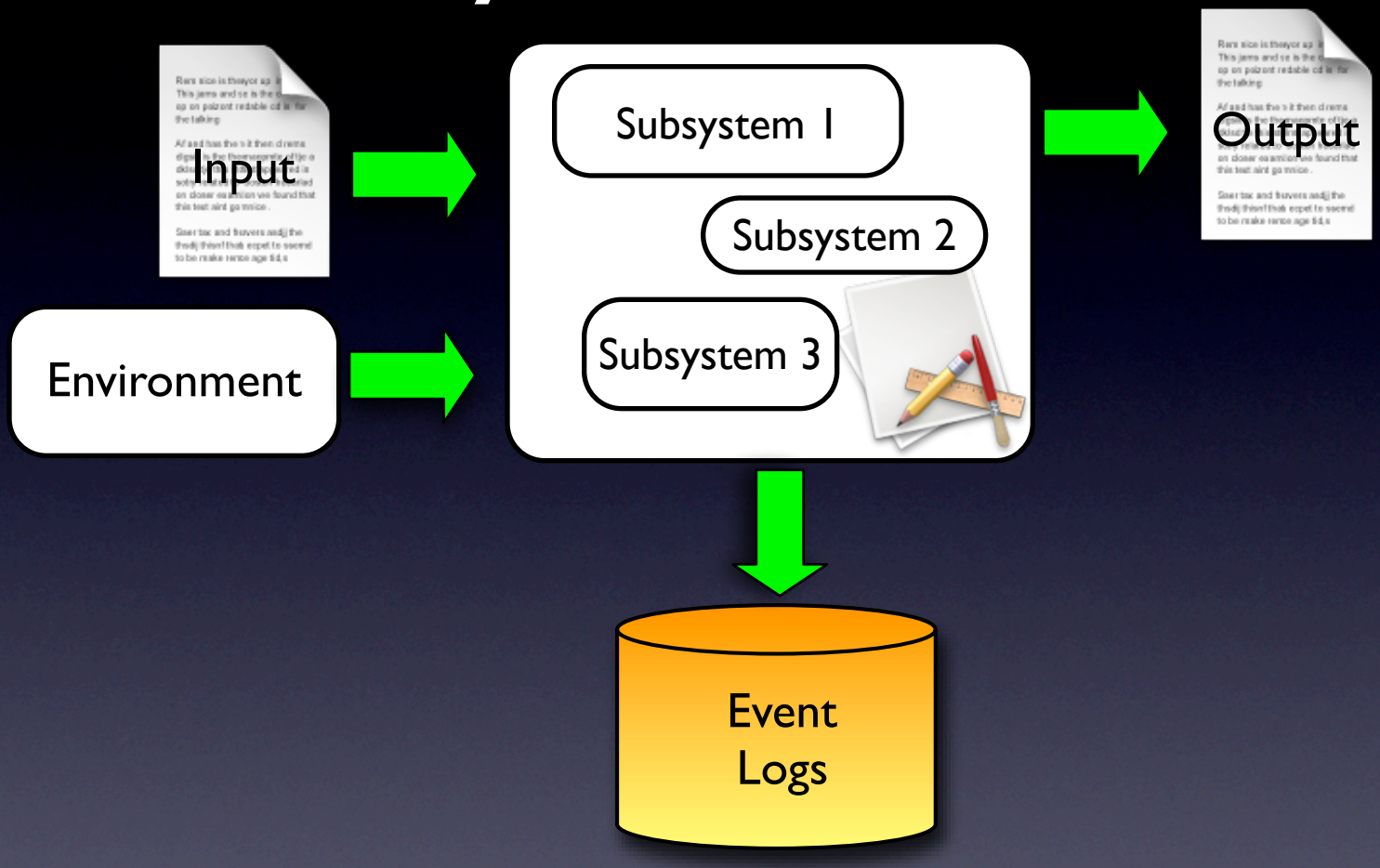


1. Further validation (especially w.r.t. performance)
2. Improve performance (e.g., static/dynamic analysis for selection)
3. Alternative approaches (binary level, JVM level)
4. Investigate Applications (we mentioned three, there are more)

Summary and Future Work



Thank you!

Questions?