# dBug: Systematic Evaluation of Distributed Systems

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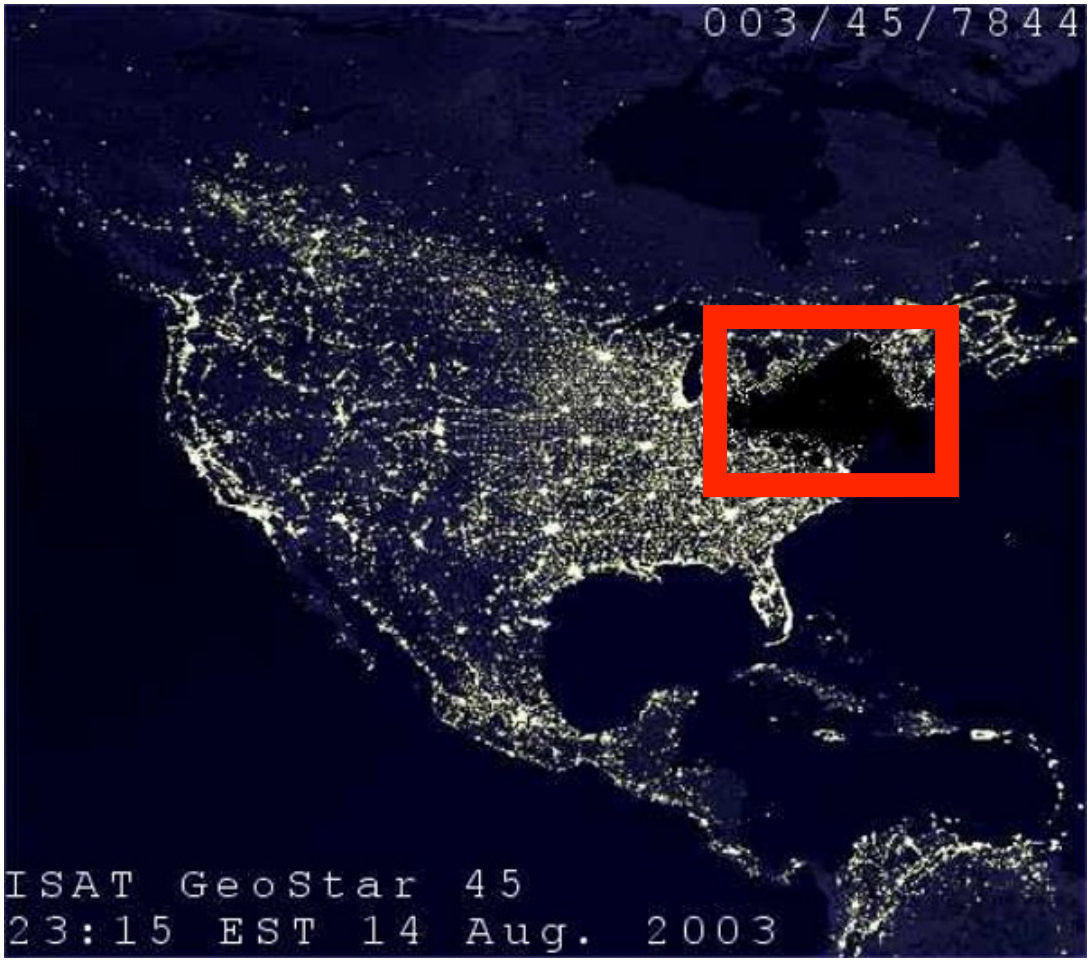
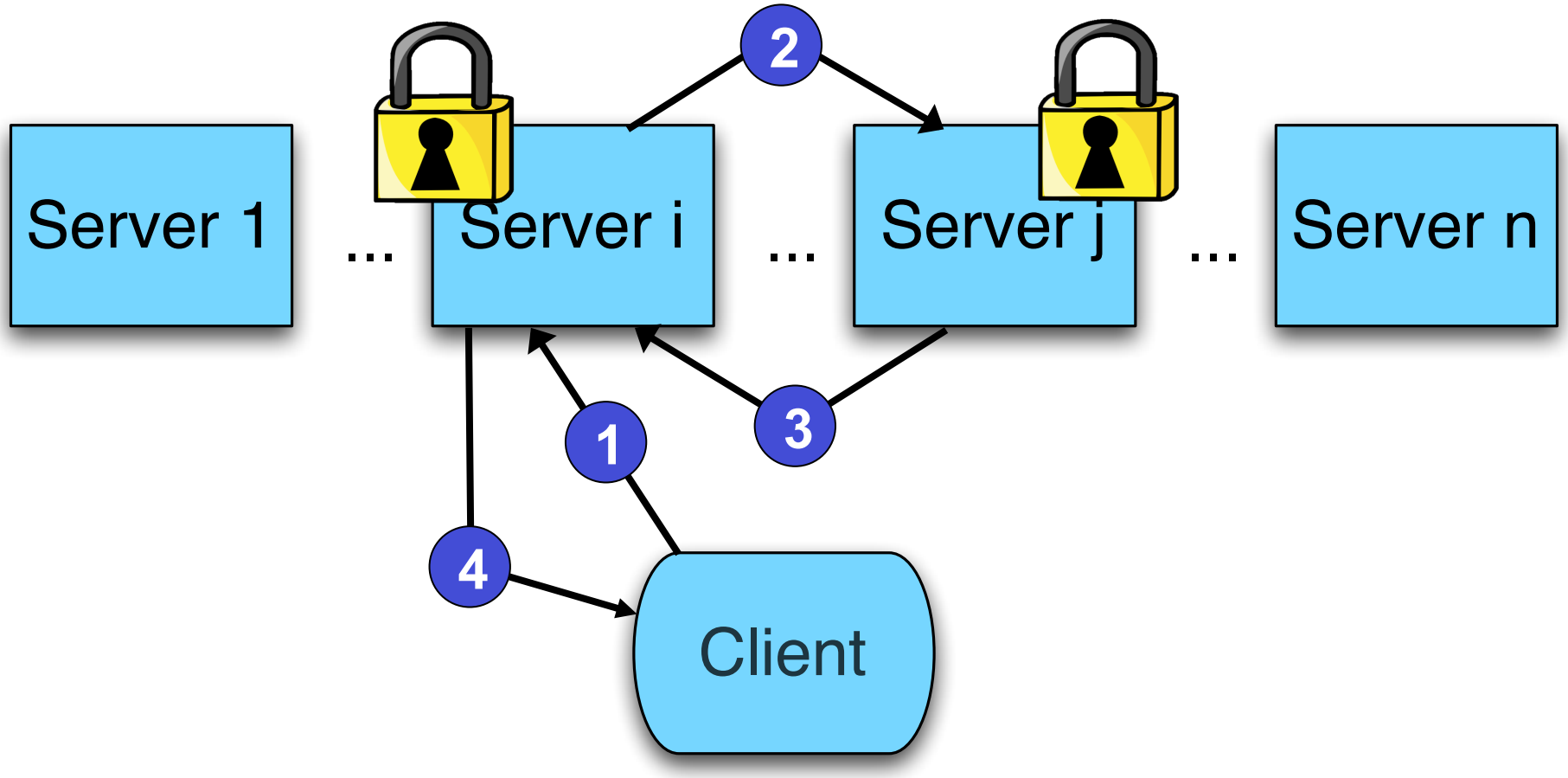
# Concurrency Bugs Everywhere



# Why Do Concurrency Bugs Exist?



# Why Do Concurrency Bugs Exist?

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# Motivating Example Lessons

- Locking across RPC = bad idea
- Explosion of possible scenarios
- Corner case errors easy to miss

- Testing concurrent systems is hard:
  - Control / Enumerate possible scenarios
  - Tackle state space explosion

# Need For Better Testing Methods

- Hardware performance 
- Software complexity 

- Formal specifications impractical
- New systems rarely written from scratch

- Common testing mechanism: stress testing
- Imprecise, falling behind

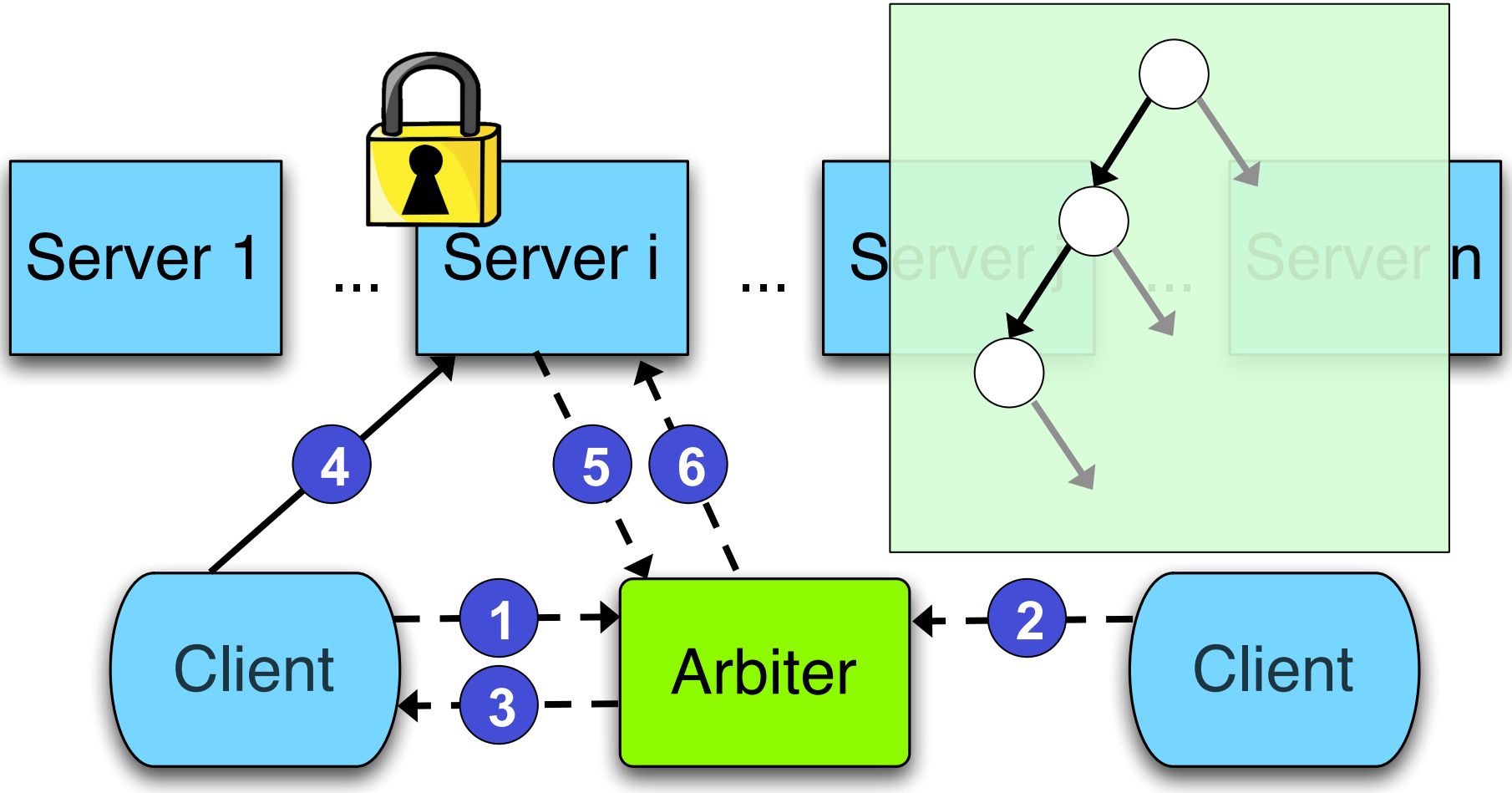
# Outline

- Motivation
- **dBug Design**
- dBug Prototype
- Prototype Case Studies
- Ongoing & Future Work
- Conclusion

# dBug Design

- Goal: Enable systematic enumeration of (all) possible execution scenarios of a test
- Repeated execution of the same test is guaranteed to explore different scenarios
- Light-weight model checking
  - Fixed initial state
  - User provided test as a specification
  - State space of the actual implementation explored

# Motivating Example dBug-ed



# dBug Design Decisions

- What events to control on and how?
- When to signal a request?
- How to (re)store a state of the system?
- How to explore the state space?
  - Parallel exploration
  - Exploration heuristics
  - State space reduction

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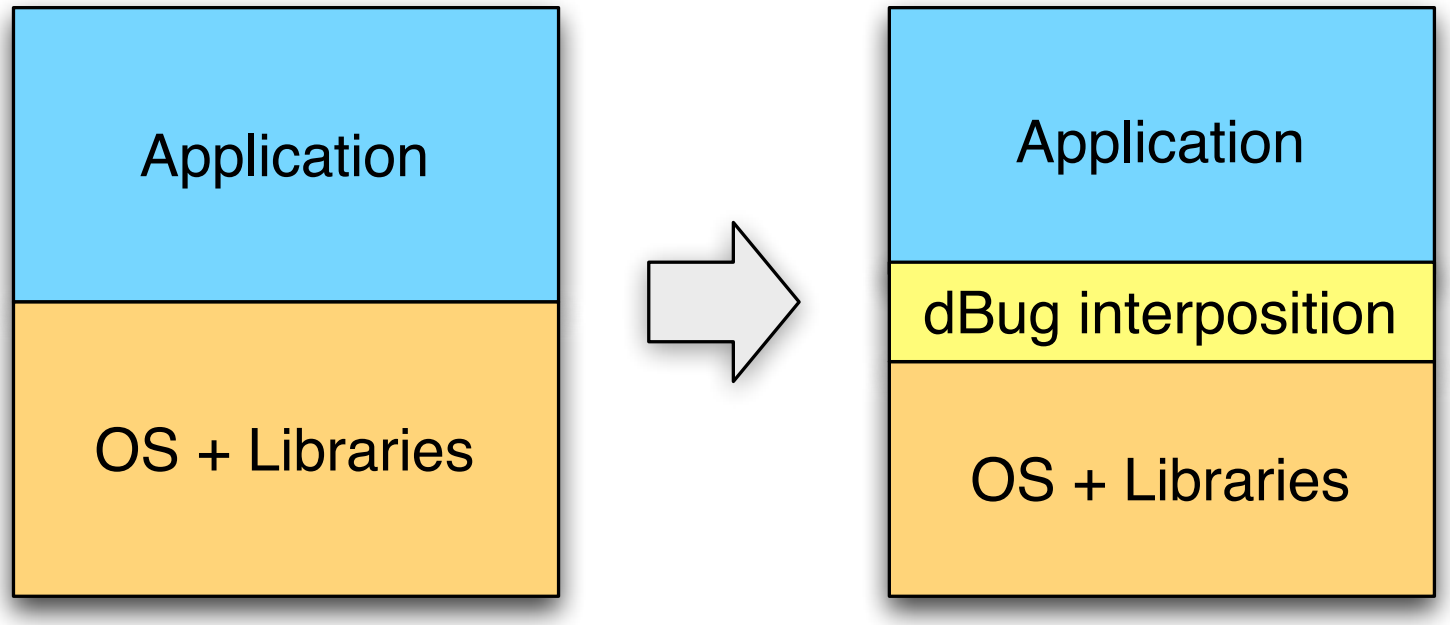
# Event Control Mechanism

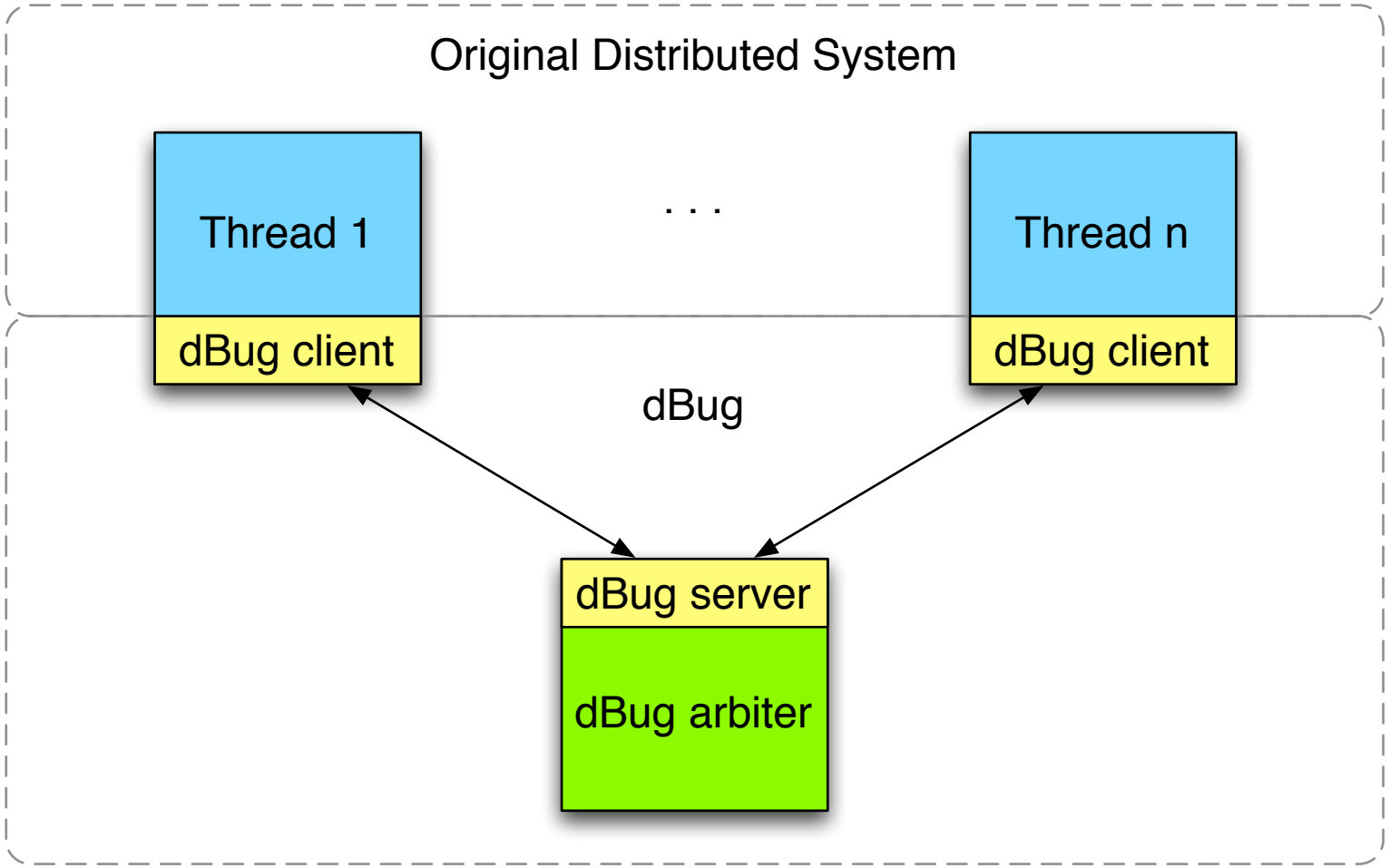


# Compile-time Interposition

Source code annotation of:

- Creation of threads (processes)
- Destruction of threads (processes)
- Coordination primitives:
  - Thread synchronization
  - Remote procedure calls
  - “Your coordination primitive here”

# Client-Server Architecture

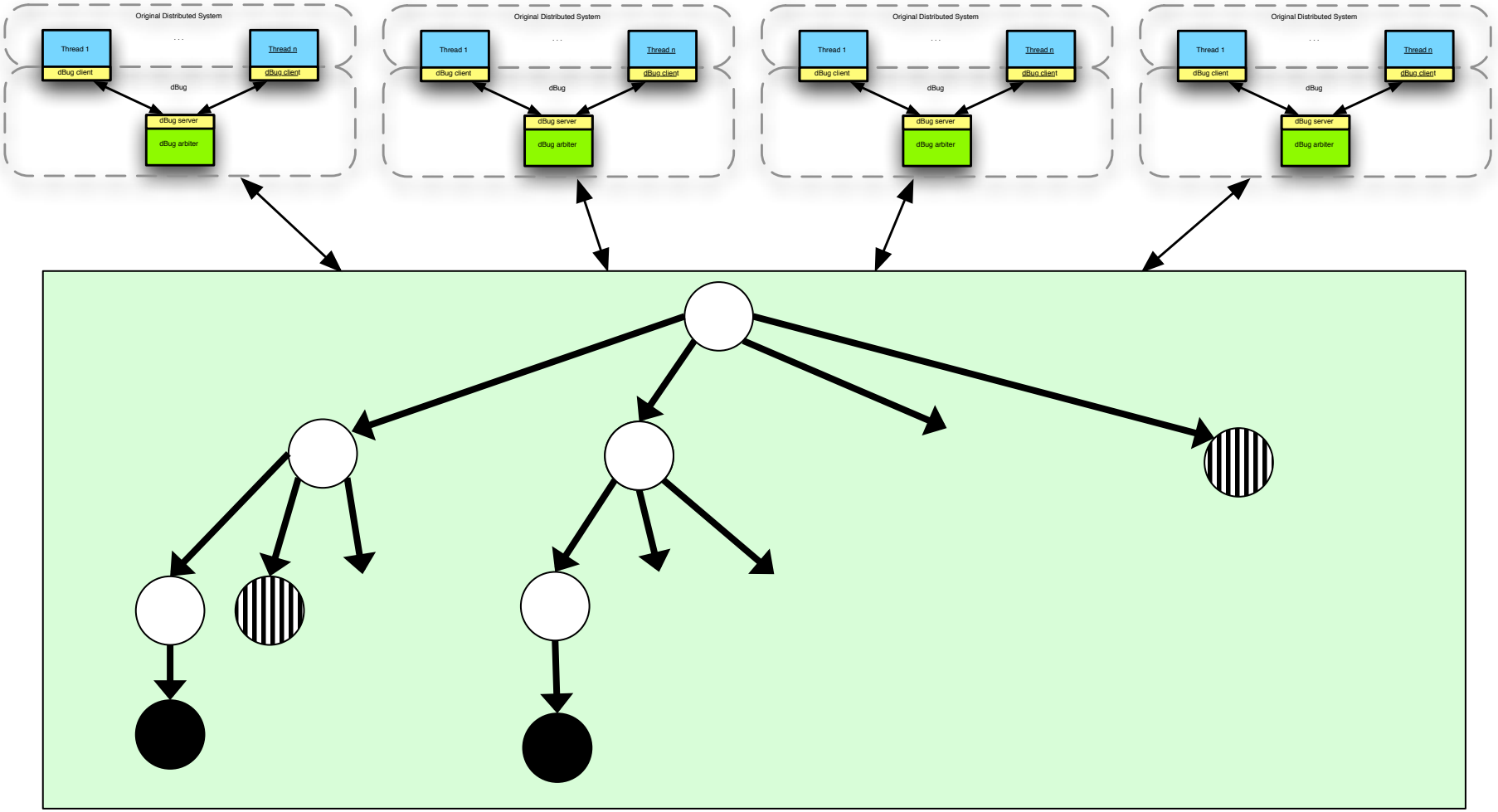


# When to Signal a Request?

- Blind Mode:
  - Uses a timeout
  - Pros: Easy to implement
  - Cons: Overhead, Imprecise

- Informed Mode
  - Uses application idle/progress hints
  - Pros: Fast, Accurate
  - Cons: Expert knowledge, Annotation

# State Space Exploration



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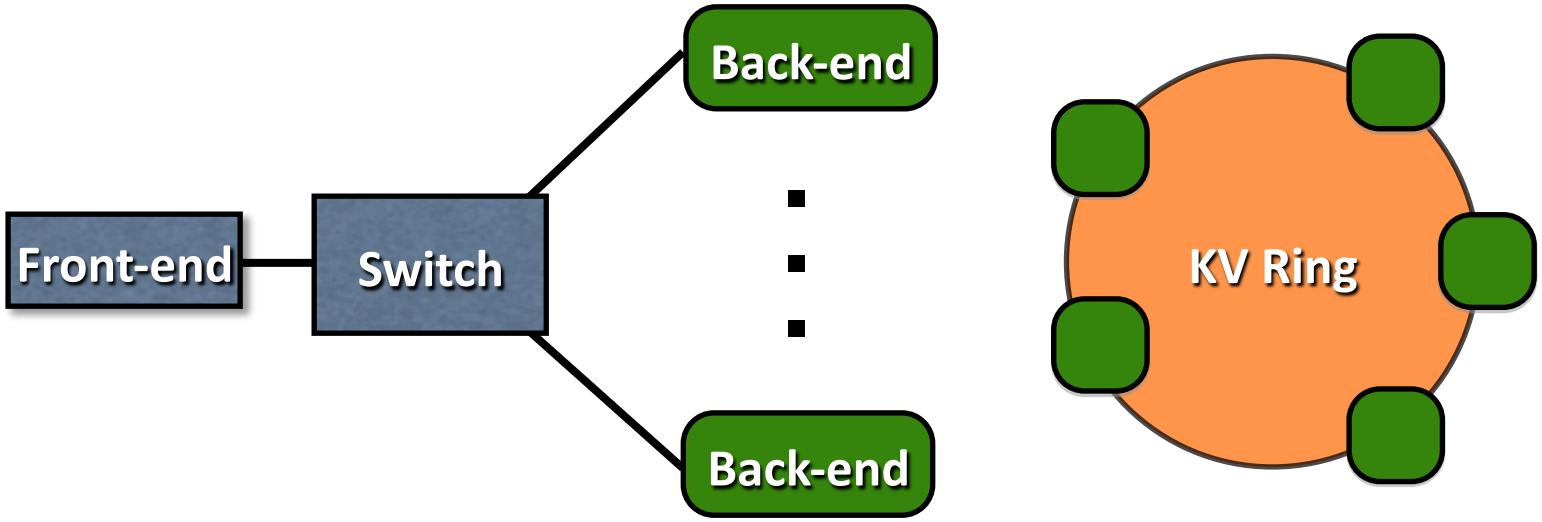
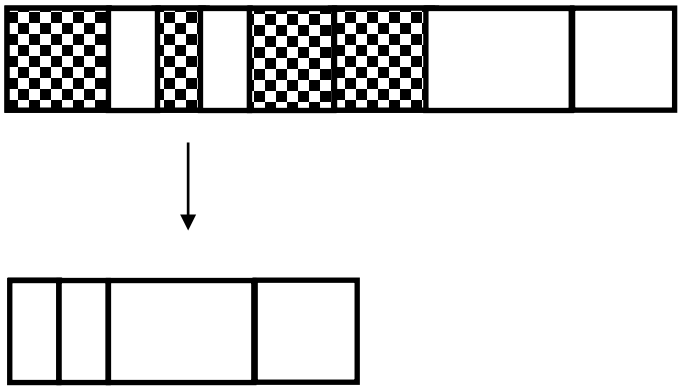
# Fast Array of Wimpy Nodes

- Energy-efficient architecture
- FAWN-KV = distributed key-value storage
- put()/get() interface, strong consistency
- get() returns value of the last acked put()



# Case Study 1: Multi-threading

Obsolete data
Up-to-date data



Log-structured writes

Need for clean-up

Rewrite Operation
- sequential scan
- atomic swap

# Integrating FAWN-KV and dBug

- Creation and destruction of threads
  - 20 lines of annotations
- Acquiring and releasing locks
  - Compile-time interposition on pthread interface
- Test case:

```
put(key,value1);
if (fork() == 0) { rewrite(); }
else { put(key,value2); get(key); }
```

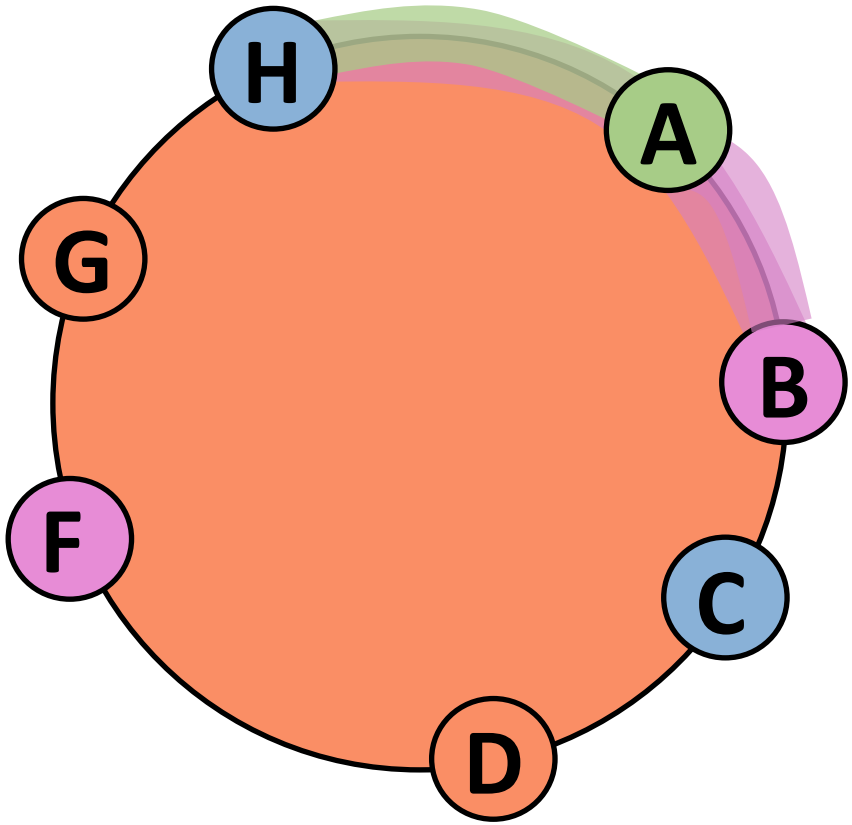
# Case Study Results

- Evaluated with the blind mode for **~24 hours**
- Over **7000** possible scenarios
- Test always executed correctly

- Introduced and detected a data race bug
- The bug showed up in **~700** scenarios

- Two person weeks of work

# Case Study 2: Including RPCs



# Integrating FAWN-KV with dBug

- Creation and destruction of agents
  - 20 lines of annotations
- Issuing remote procedure calls
  - Modified Apache Thrift library (2 lines)
- Test case:

```
put(key,value1);
If (fork() == 0) { join(); }
else { if (fork() == 0) put(key,value2); else get(key); }
```

# Case Study Results

- Evaluated with blind mode for **45 minutes**
- Total of **173** possible scenarios
- Found a bug

- The bug showed up in only **3** scenarios
- get(key) returns “not found”

- Two person weeks of work

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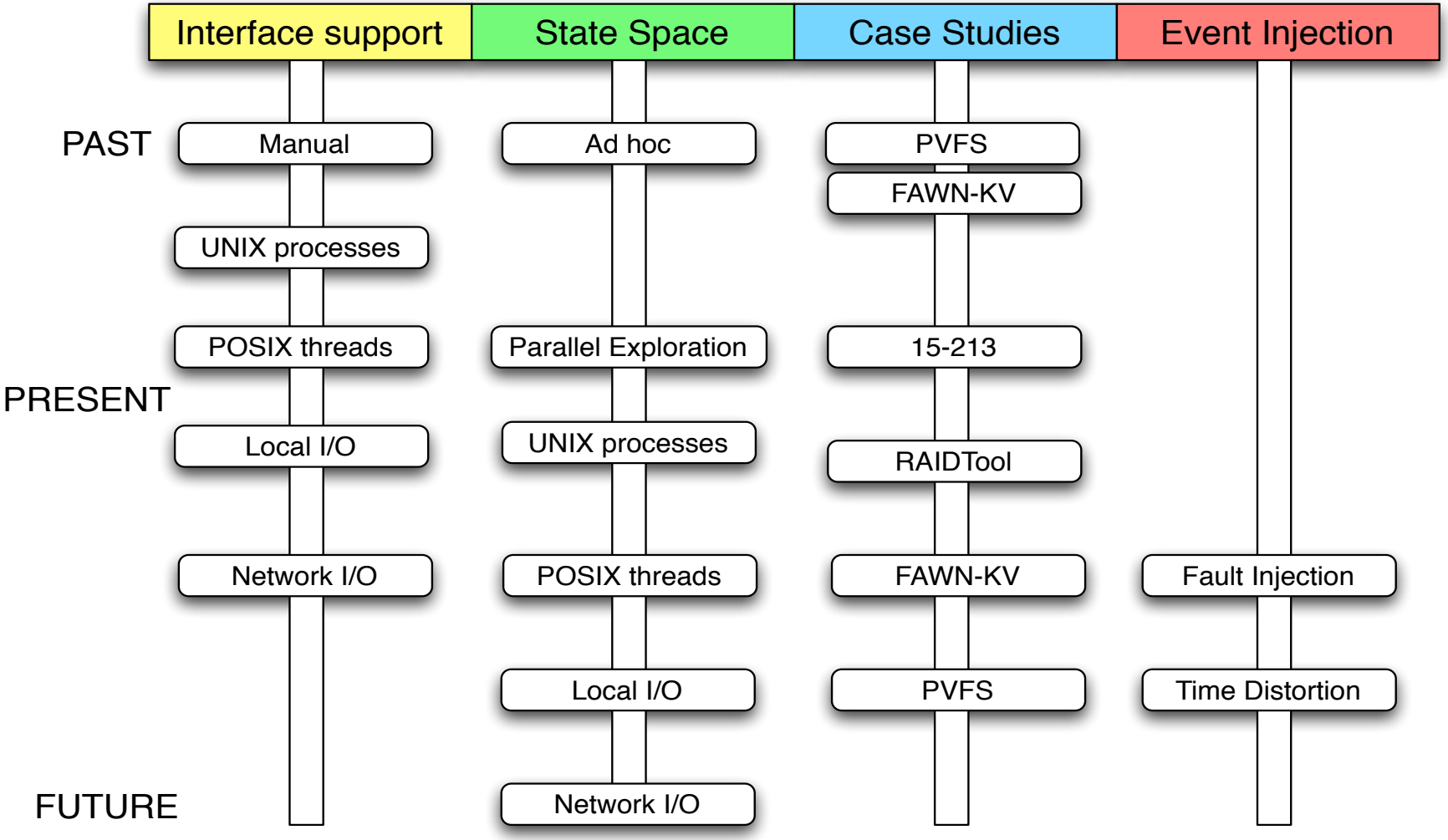
# dBug Evolution

# dBug 2nd Generation

- Open source Autotools project
- dBug interposition as a shared library
- Precise and automatic detection of when to signal a request

- Educational use of dBug:
  - In use to evaluate student solutions for 15-213
  - Found bugs in the TA implementation
  - Available to students to test their solutions

# Future Work


Interface support
State Space
Case Studies
Event Injection
PAST
PRESENT
FUTURE
Manual
UNIX processes
POSIX threads
Local I/O
Network I/O
Ad hoc
Parallel Exploration
UNIX processes
POSIX threads
Local I/O
Network I/O
PVFS
FAWN-KV
15-213
RAIDTool
FAWN-KV
PVFS
Fault Injection
Time Distortion

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# Related Work

- Verisoft [Godefroid98]
  - manual, exhaustive, multi-threaded, C and C++ sources
- MaceMC [Killian07]
  - automated, selective, distributed, Mace sources
- CHESS [Musuvathi08]
  - automated, selective, multi-threaded, Windows binaries
- MoDist [Yang09]
  - automated, selective, distributed, Windows binaries

# Conclusion

- Systematic and automatic evaluation of distributed system test cases
- Open source implementation of dBug
- Experiments with:
  - Parallel Virtual File System (C)
  - FAWN-based key value storage (C++)
  - CMU student class projects (C and C++)
  - RAIDTool (Java)
- Finding real bugs

# References


- **[Godefroid98]** P. Godefroid, VeriSoft: A Tool for the Automatic Analysis of Concurrent Reactive Software, CAV 1997.
- **[Killian07]** C. Killian, J. W. Anderson, R. Jhala, and A. Vahdat: Life, Death, and the Critical Transition: Detecting Liveness Bugs in Systems Code, NSDI 2007.
- **[Musuvathi08]** M. Musuvathi, S. Qadeer, T. Ball, G. Basler, P. A. Nainar, I. Neamtiu. Finding and Reproducing Heisenbugs in Concurrent Programs, OSDI 2008.
- **[Yang09]** J. Yang, T. Chen, M. Wu, Z. Xu, X. Liu, H. Lin, M. Yang, F. Long, L. Zhang, L. Zhou: MODIST: Transparent Model Checking of Unmodified Distributed Systems, NSDI 2009.
- **[Simsa10]** J. Simsa, G. Gibson, R. Bryant: dBug: Systematic Evaluation of Distributed Systems, SSV 2010.