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How To Keep Your Head Above Water While Detecting Errors

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Impact of Failures in Internet Services

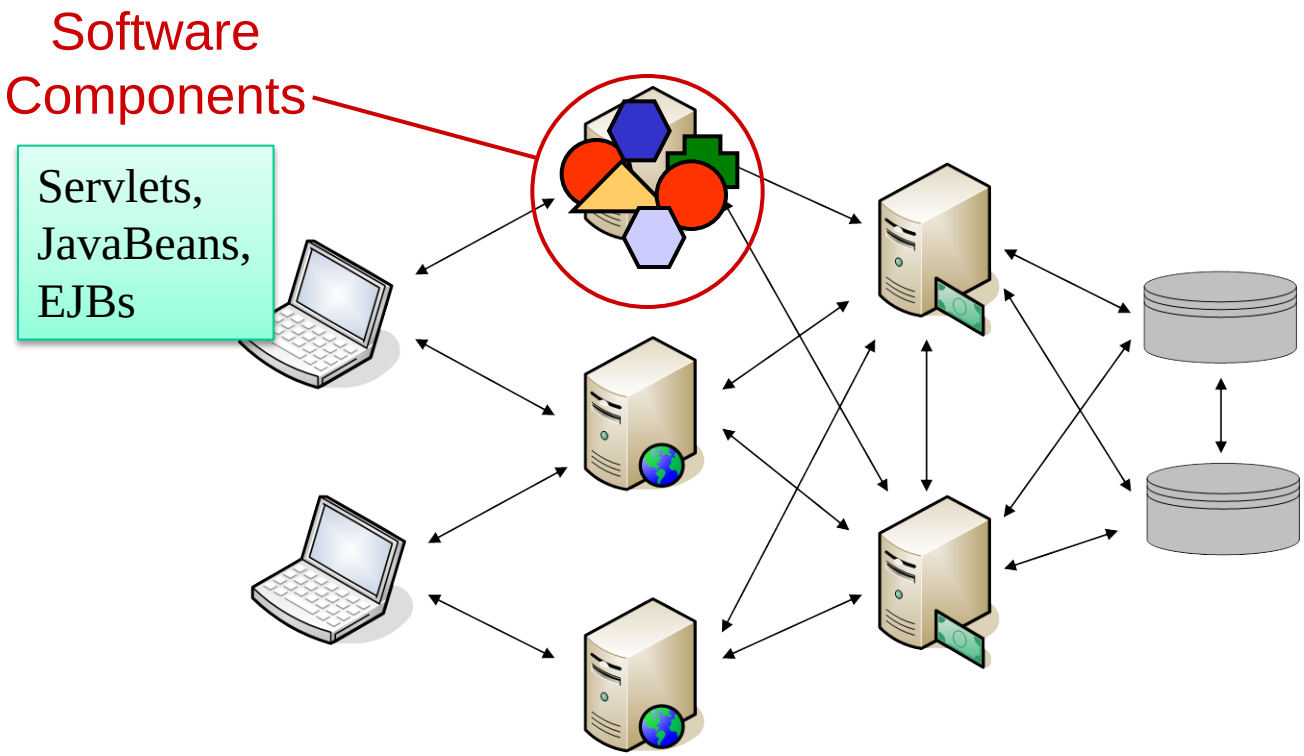
- Internet services are expected to be running 24/7
  - System downtime can cost **$1 million** / hour

    (Source: Meta Group, 2002)

- *Service degradation* is the most frequent problem
  - Service is slower than usual; almost unavailable
  - Can be difficult to detect and diagnose

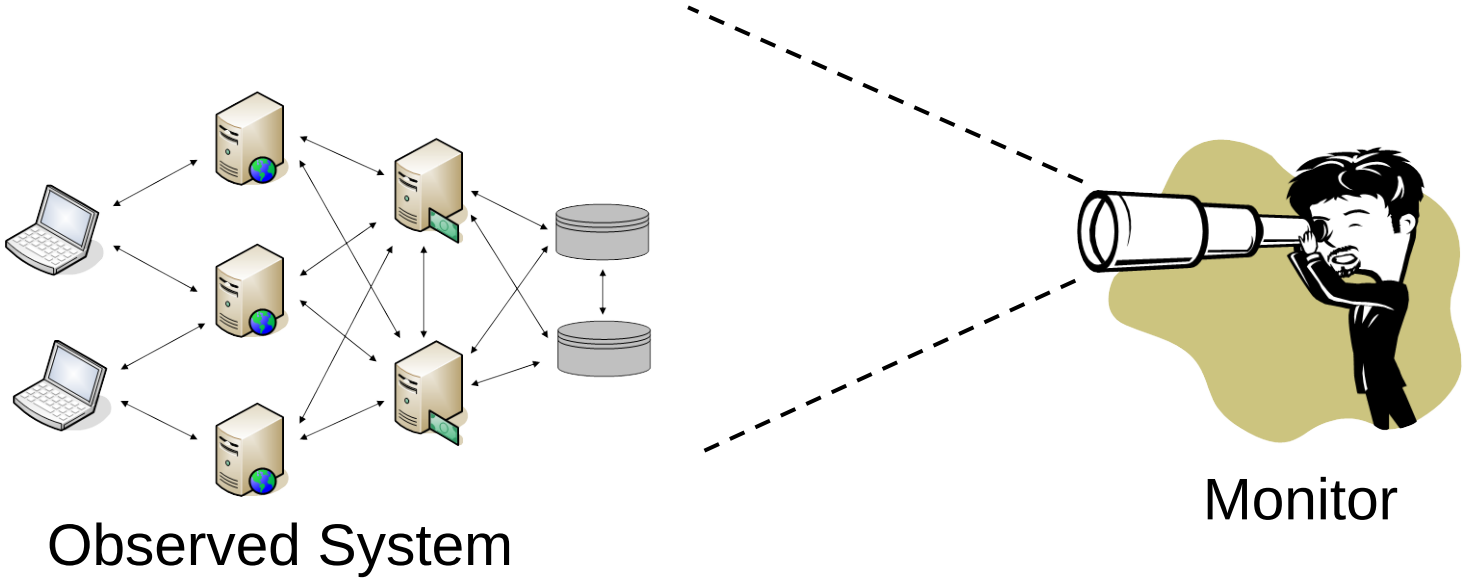
- Internet-based applications are very large and dynamic
  - Complexity increases as new components are added

Complexity of Internet-based Applications



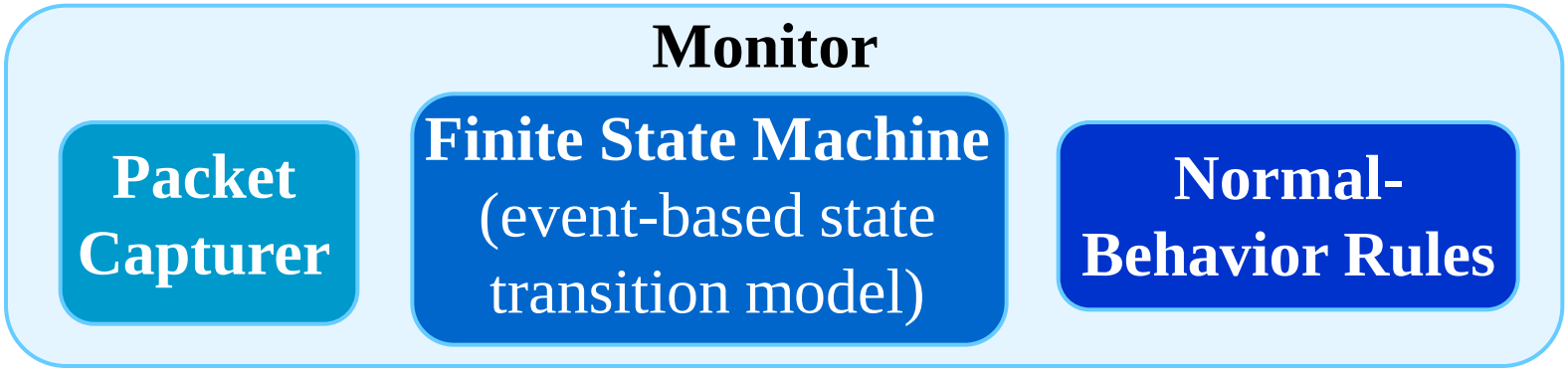
- Each tier has multiple components
- Components can be stateful

The *Monitor* Detection System (*TDSC '06*)



- ***Non-intrusive*** — observe messages between components
- ***Online*** — faster detection than offline approaches
- ***Black-box detection*** — components treated as *black boxes*
  - No knowledge of components' internals

Stateful Rule-based Detection

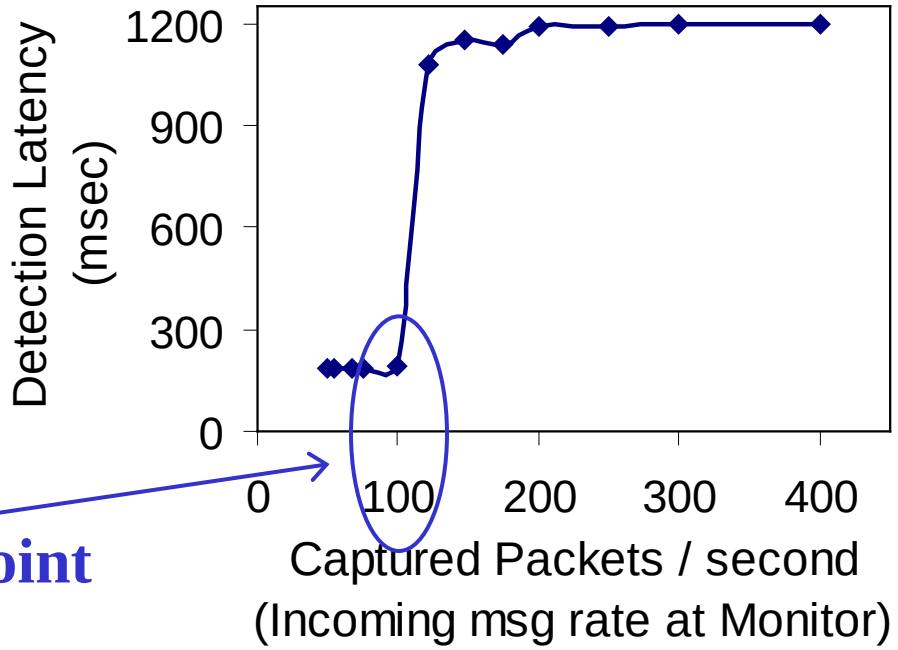


Detection Process

A *message* is captured → Deduce current application *state* → Match rules based on the deduced *state* → If a rule does not satisfy, signal *alarm*

1 2 3 4

The *Breaking Point* in High Rate of Messages



- After breaking point, latency increases sharply
- True alarms rate decreases because packets are dropped
- Breaking point expected in any stateful detection system

Avoiding the Breaking Point: *Random Sampling* (SRDS '07)

- *Processing Load* in Monitor

$$\delta = R \times C$$

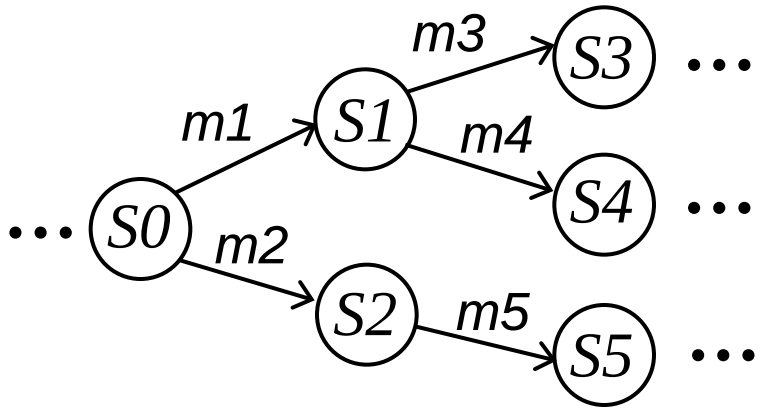
R: Incoming message rate, C: Processing cost per message

- Processing Load δ is reduced by reducing R
  - Only a portion of incoming messages is processed
  - n out of m messages are *randomly sampled*

- Sampling is activated if $R \geq$ *breaking point*

The *Non-Determinism* Caused by Sampling

A portion of a Finite State Machine



Events in Monitor

(1) SV = { *S0* }
(2) A message is dropped
(3) SV = { *S1*, *S2* }
(4) A message is sampled
(5) The message is *m5*
(6) SV = { *S5* }

Definitions:

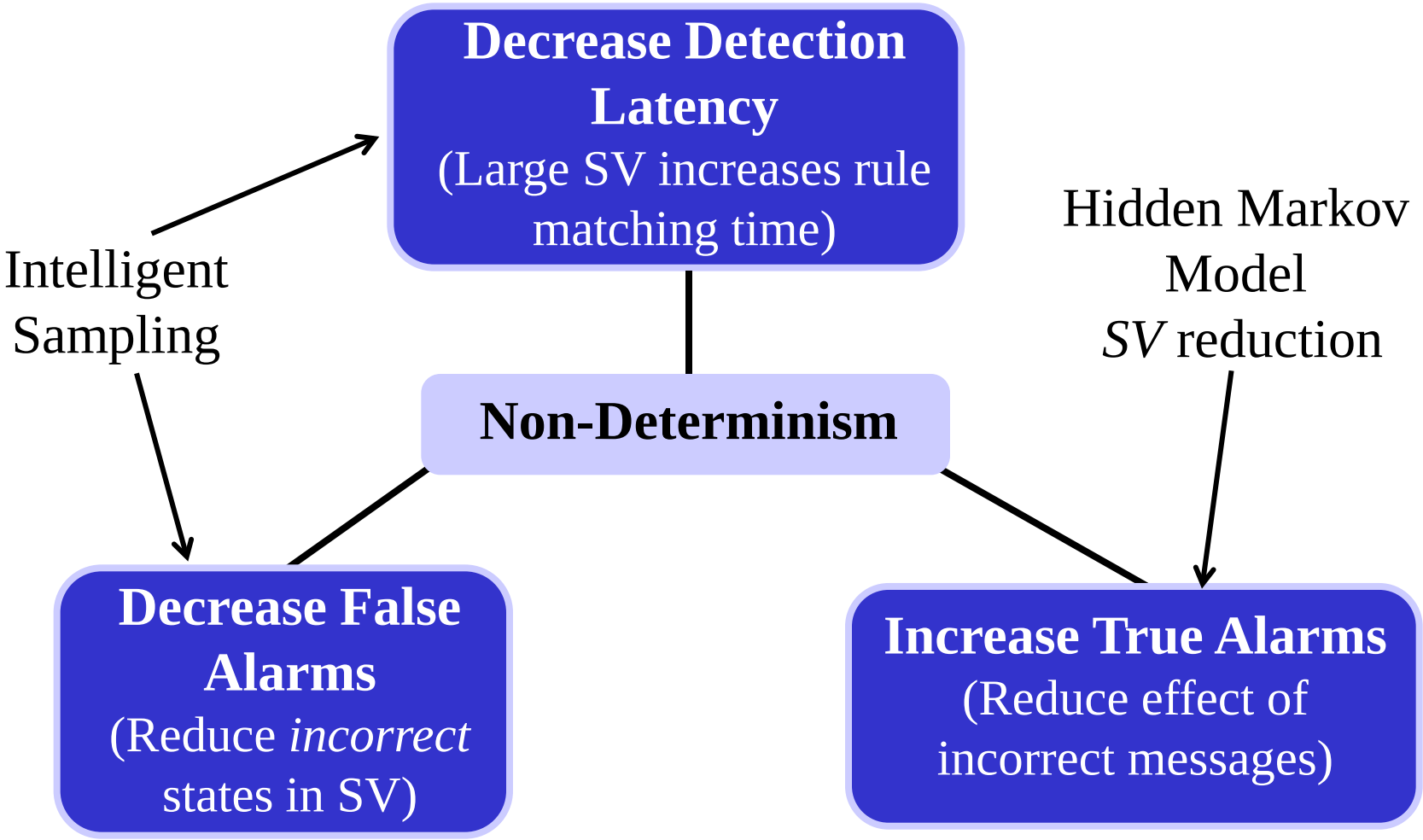
State Vector (SV) — The state(s) of the application from Monitor's point of view (deduced state(s))

Non-Determinism — Monitor is no longer aware of the exact state the application is in (because of dropped messages)

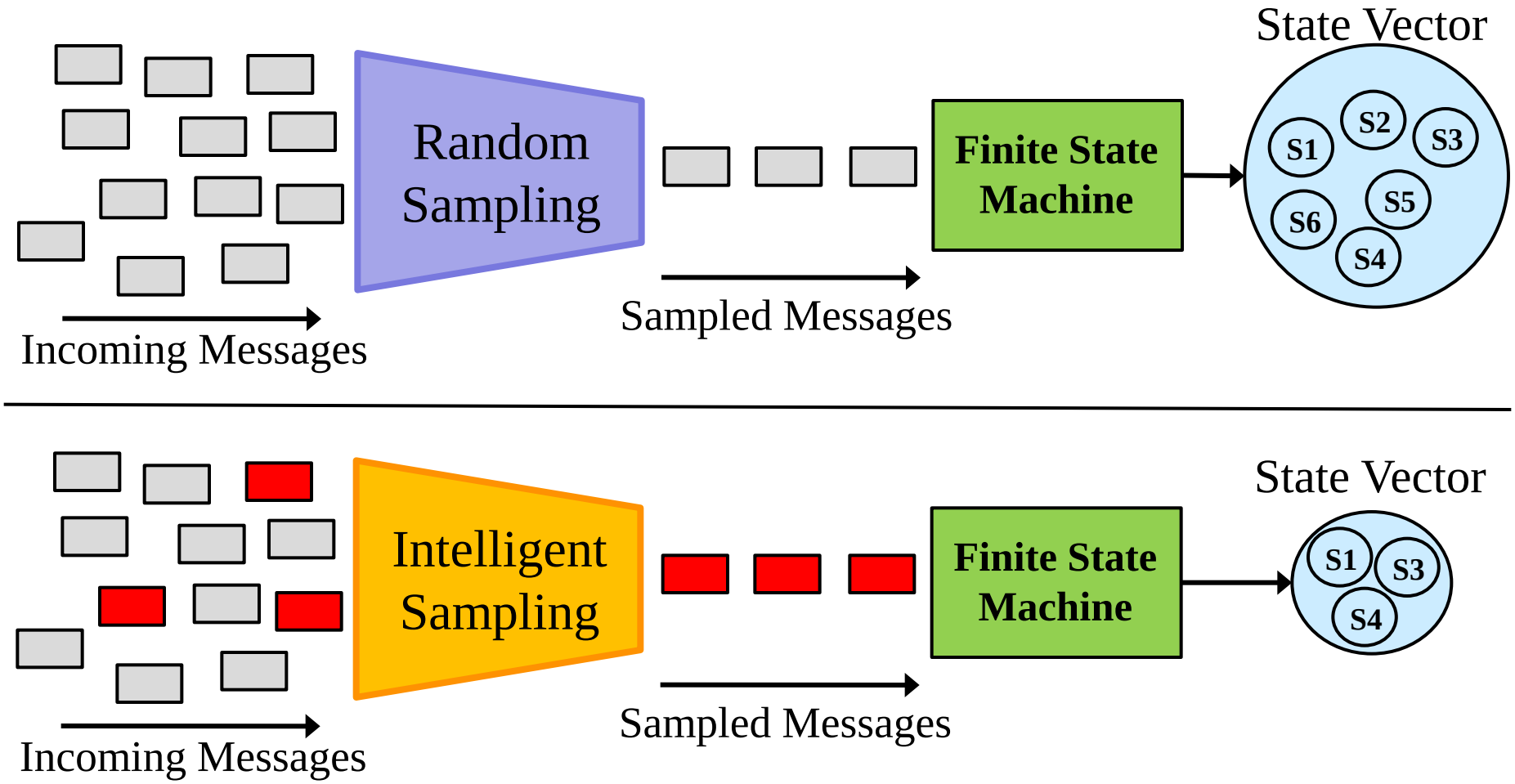
Remaining Agenda

I. Addressing the problem of *non-determinism*
   A. Intelligent Sampling
   B. Hidden Markov Model (HMM) for state determination
II. Experimental Test-bed
III. Performance Results
IV. Efficient Rule Matching and Triggering

Challenges with Non-Determinism



Intelligent Sampling

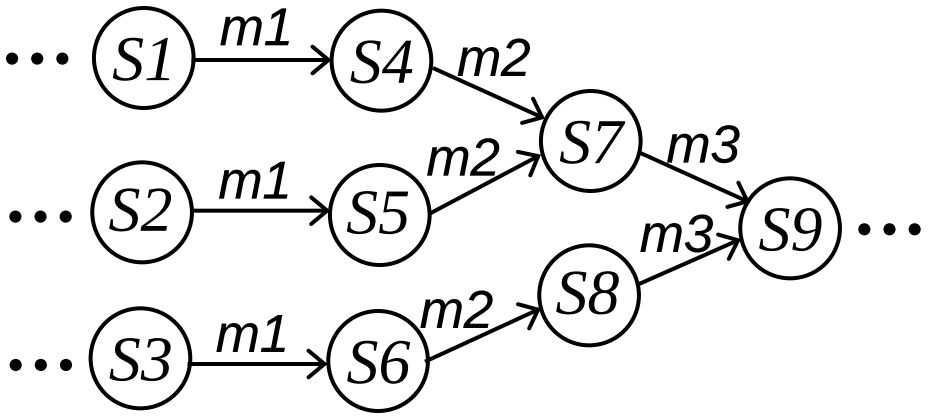


Message with *desirable* property

What is a Desirable Property of a Message?

Suppose, *SV* ={ *S1*, *S2*, *S3* }, *Sampling Rate* = 1/3

A portion of a Finite State Machine



Sampled Message	SV	Discriminative Size
m1	{*S4*, *S5*, *S6*}	3
m2	{ *S7*, *S8* }	2
m3	{ *S9* }	1

Discriminative Size — Number of times a message appears in transitions to different states in the FSM

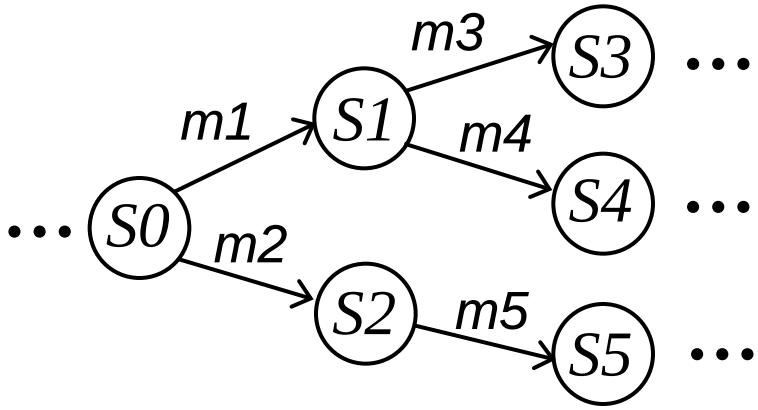
- Desirable property is a small *discriminative size*

Benefits of Intelligent Sampling

Random Sampling	Intelligent Sampling
• *SV* can grow into large size	• *SV* is kept small – Detection latency reduction
• Multiple incorrect states – Increase of false alarms	• Less incorrect states in *SV* – False alarms reduction

The Problem of Sampling an *Incorrect Message*

- What if an *incorrect* message is sampled?
  - The message is *incorrect* in current states, e.g., a message from buggy component



- Suppose *SV* = { *S1*, *S2* } and *m3* is changed to *m5*

  ⇒ *SV* = { *S5* } (incorrect *SV*!, it should be { *S3* })

Probabilistic State Vector Reduction: *A Hidden Markov Model Approach*

- Hidden Markov Model (HMM) used to reduce SV
  - An HMM is an extended ***Markov Model*** where states are not observable
  - States are hidden as in the monitored application
- Given an HMM, we can ask:

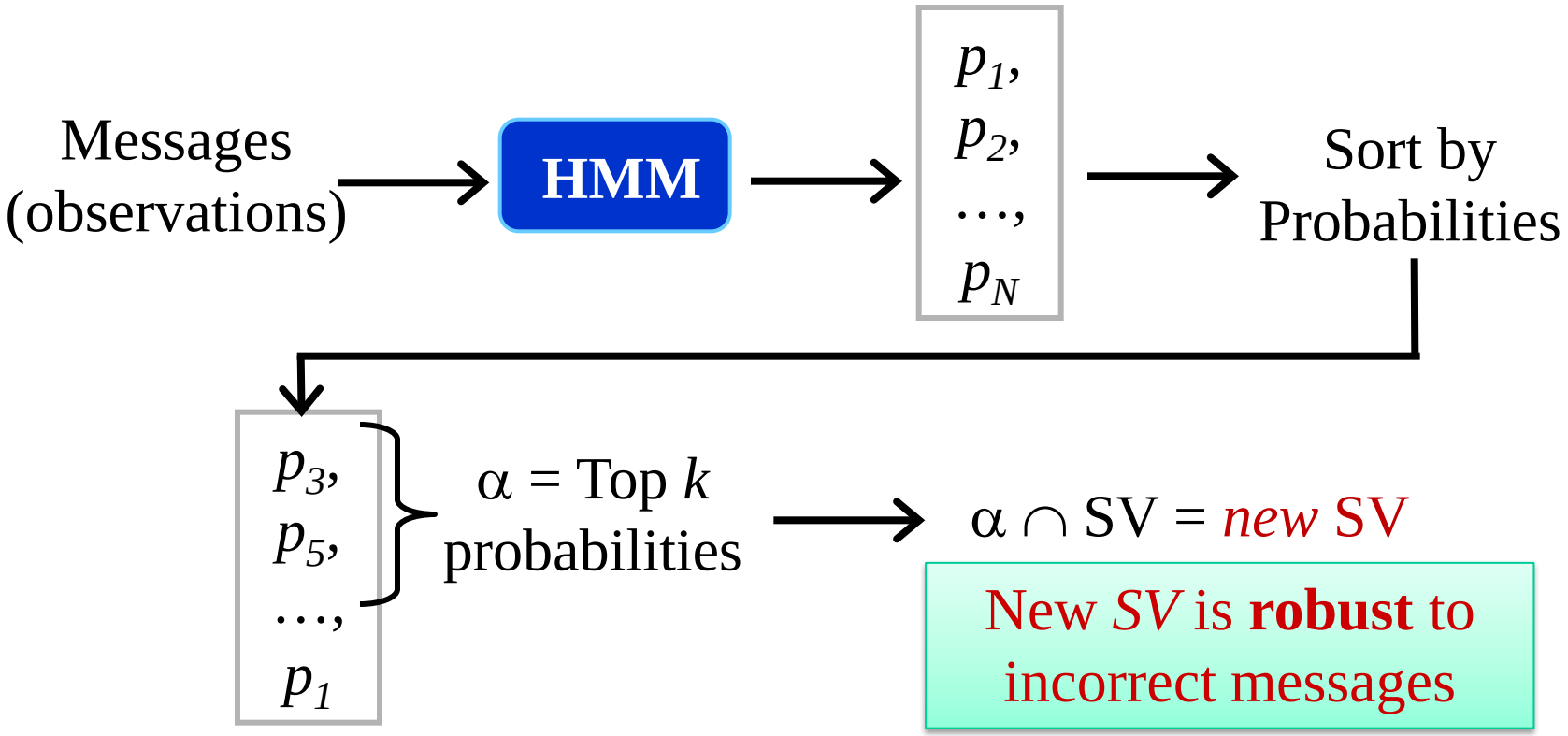
  The probability of the application being in any state, given a sequence of messages?

  Cost is $\mathbf{O}(N^3L)$, N: number of states L: sequence length
- The HMM is trained (offline) with application traces

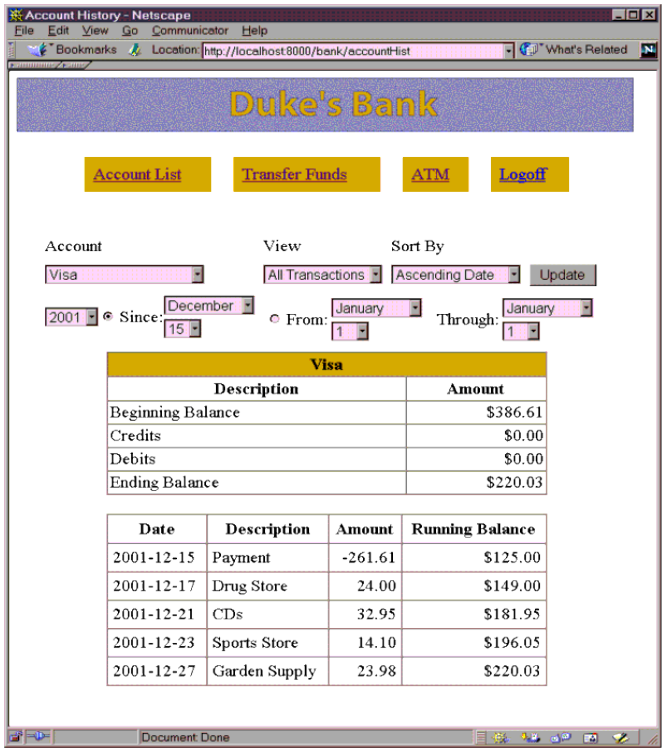
State Vector Reduction with the HMM

- Monitor asks the HMM: $\{p_1, p_2, \ldots, p_N\}$

  $p_i = P(S_i \mid O)$, S_i: application state i, O: observation's sequence

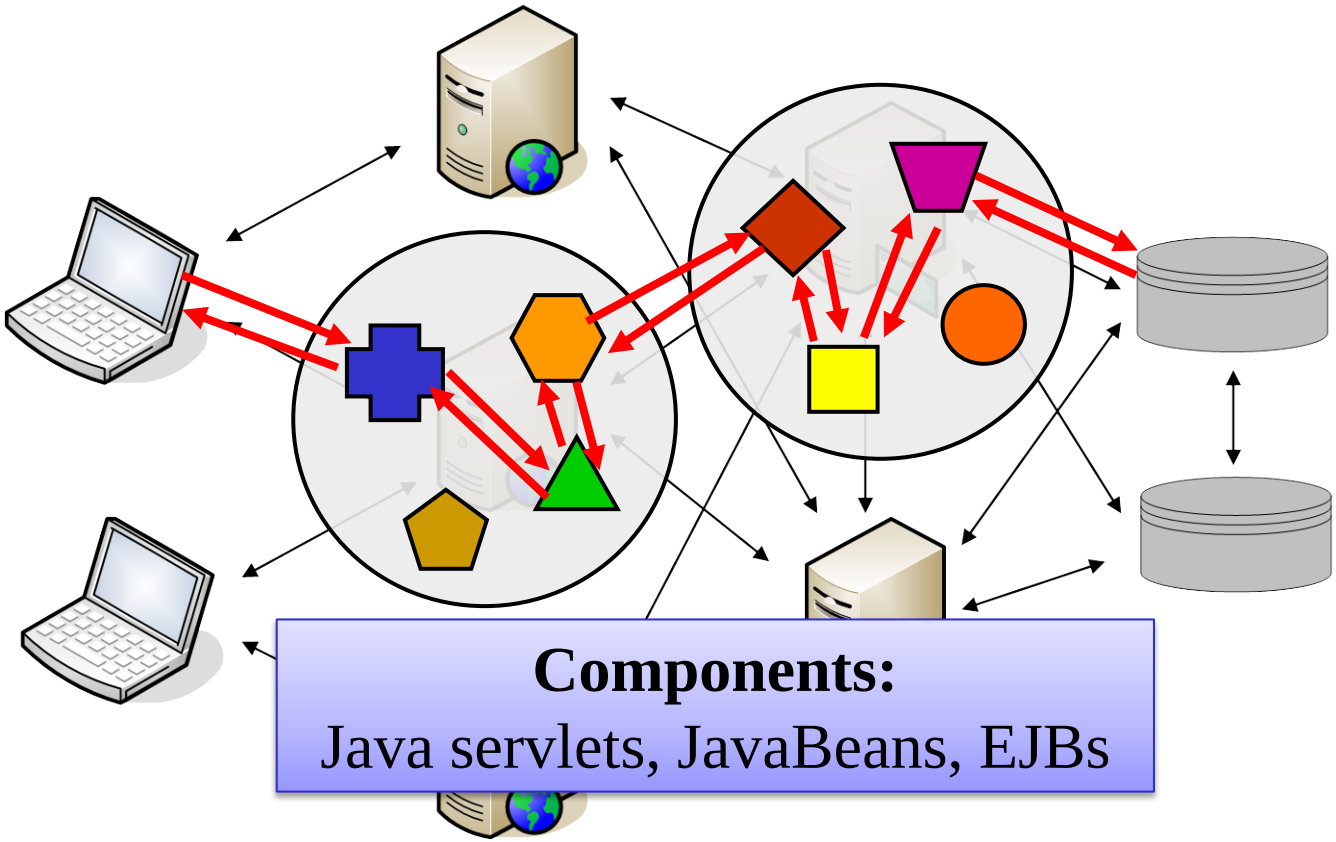


Experimental Testbed: Java Duke's Bank Application



- Simulates multi-tier online banking system
- User transactions:
  - Access account information, transfer money, etc.
- Application stressed with different workloads
  - Incoming message rate at Monitor varies with user load

Web Interaction: A Sequence of *calls* and *returns*



Components:
Java servlets, JavaBeans, EJBs

Error Injection Types

Error Type	Description
Response Delays	a response delay in a method call
Null calls	a call to a component that is never executed
Unhandled Exceptions	exception thrown by execution that is never caught by the program
Incorrect Message Sequences	change randomly the web interaction structure

- Errors are injected in components touched by web interactions
  - A web interaction is faulty if at least one of its components is faulty

Performance Metrics Used in Experiments

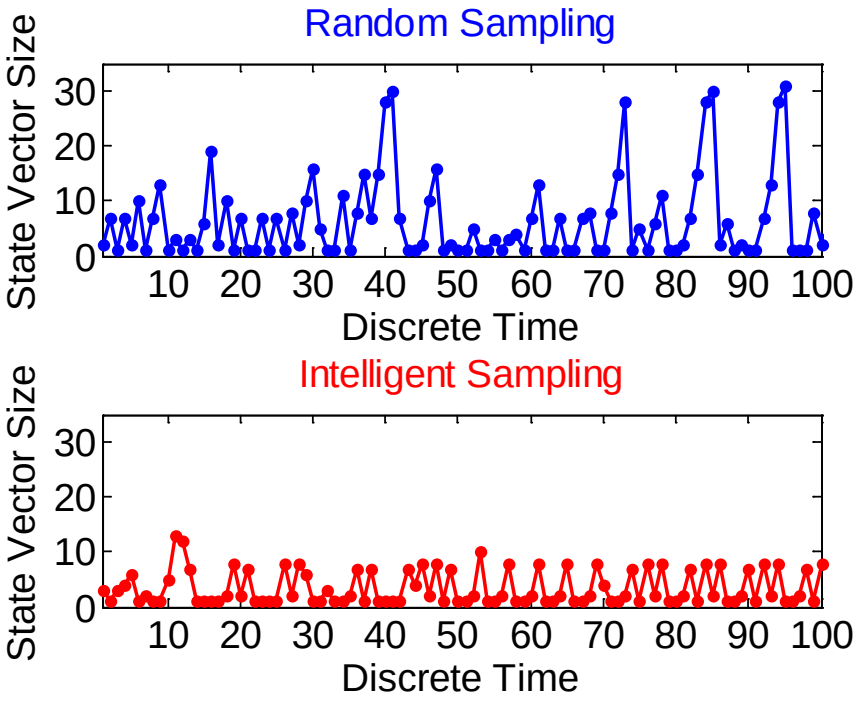
Accuracy (True Alarms)	% of *true* detections out of web interactions where errors were injected
Precision (False Alarms)	% of *true* detections out of the total number of detections
Detection Latency	time elapsed between the error injection and its detection

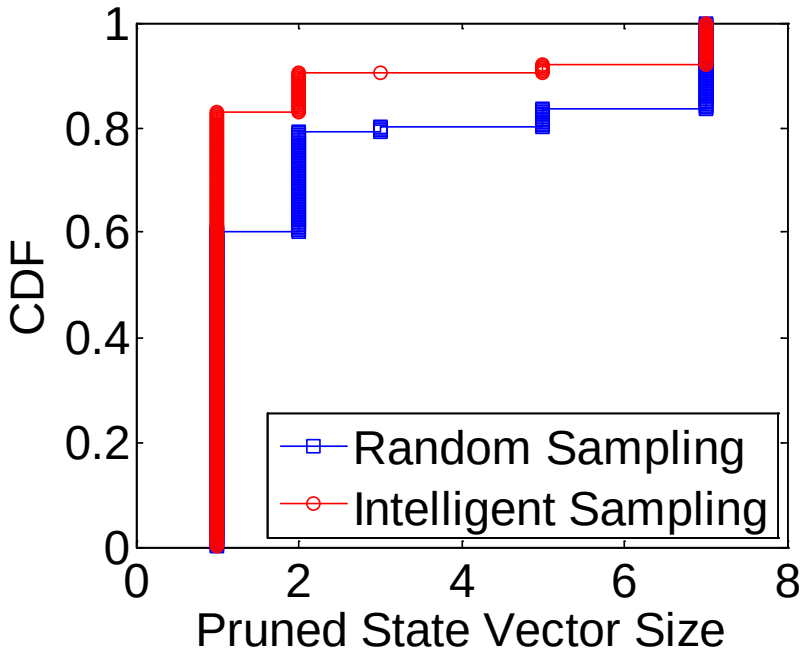
Example:

	Web Interactions				
	1	2	3	4	5
Error Injected		X	X		X
Detection (An alarm is signaled)	X	X		X	X

Accuracy = 2/3 = 0.67 **Precision** = 2/4 = 0.5

Results: State Vector Reduction

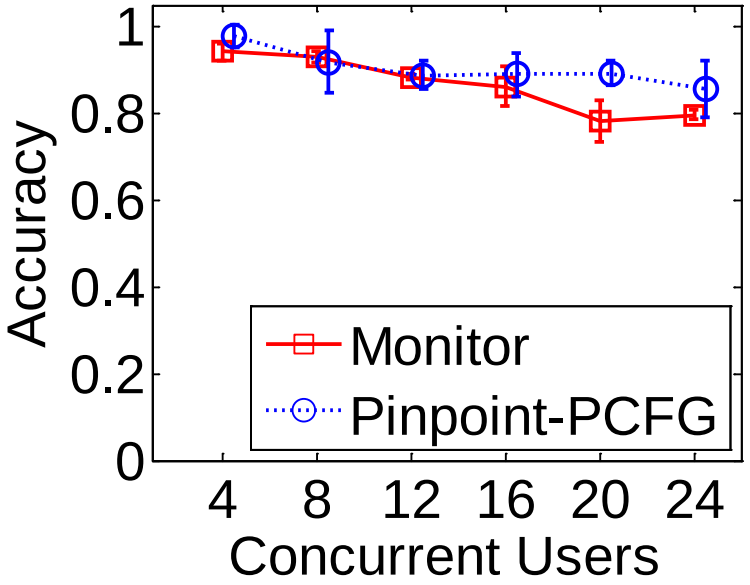


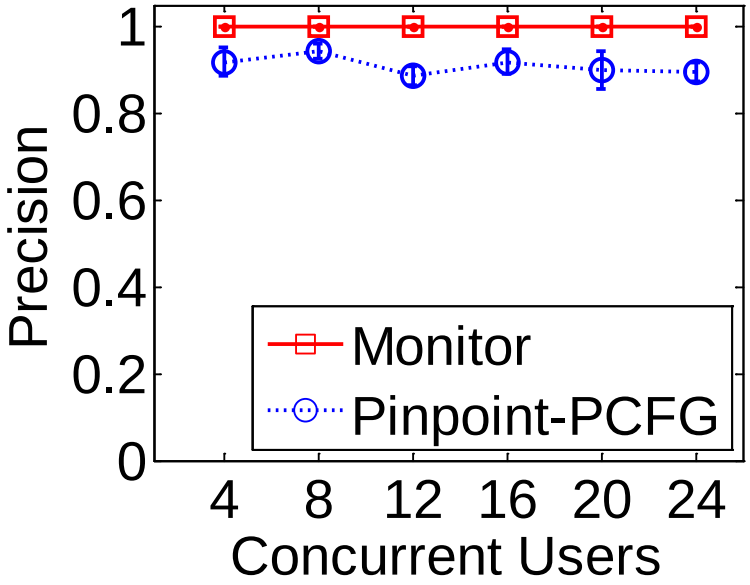


- Peaks are not observed in intelligent sampling (IS)
  - IS capability of selecting messages with small discriminative size
- SV of size 1 is more frequent in IS

Results: Monitor vs. Pinpoint (Accuracy, Precision)

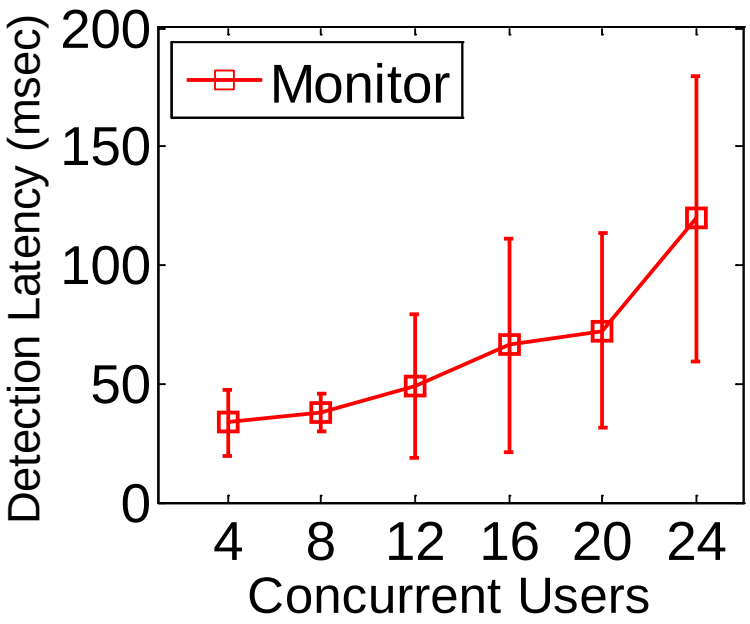
- **Pinpoint** (*NSDI* '04), traces paths though multiple components
- Use of **PCFG** to detect abnormal paths

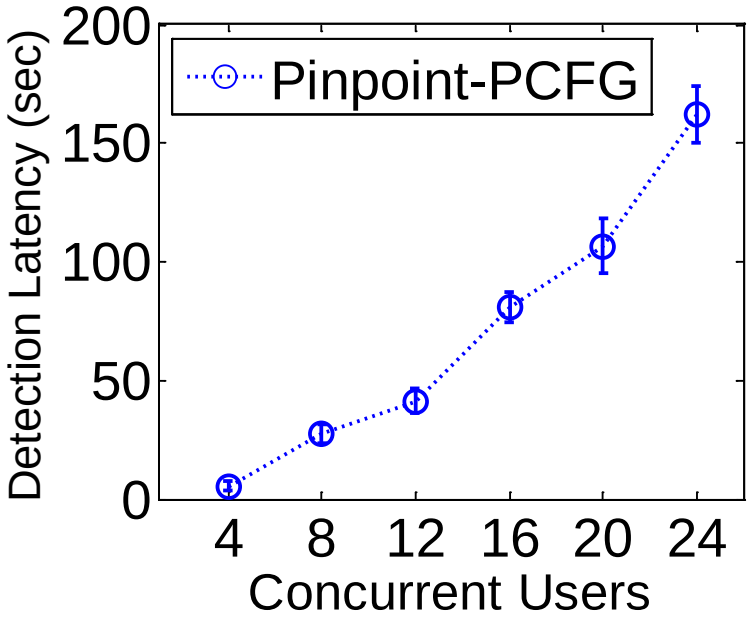




- Monitor and Pinpoint expose similar levels of accuracy
- Precision in Monitor (1.0) is higher than in Pinpoint (0.9)

Results: Monitor vs. Pinpoint (Detection Latency)





- Detection latency in Monitor is in the order of **milliseconds**, while in Pinpoint is in **seconds**
- The PCFG has a high space and time complexity

Results: Memory Consumption (MB)

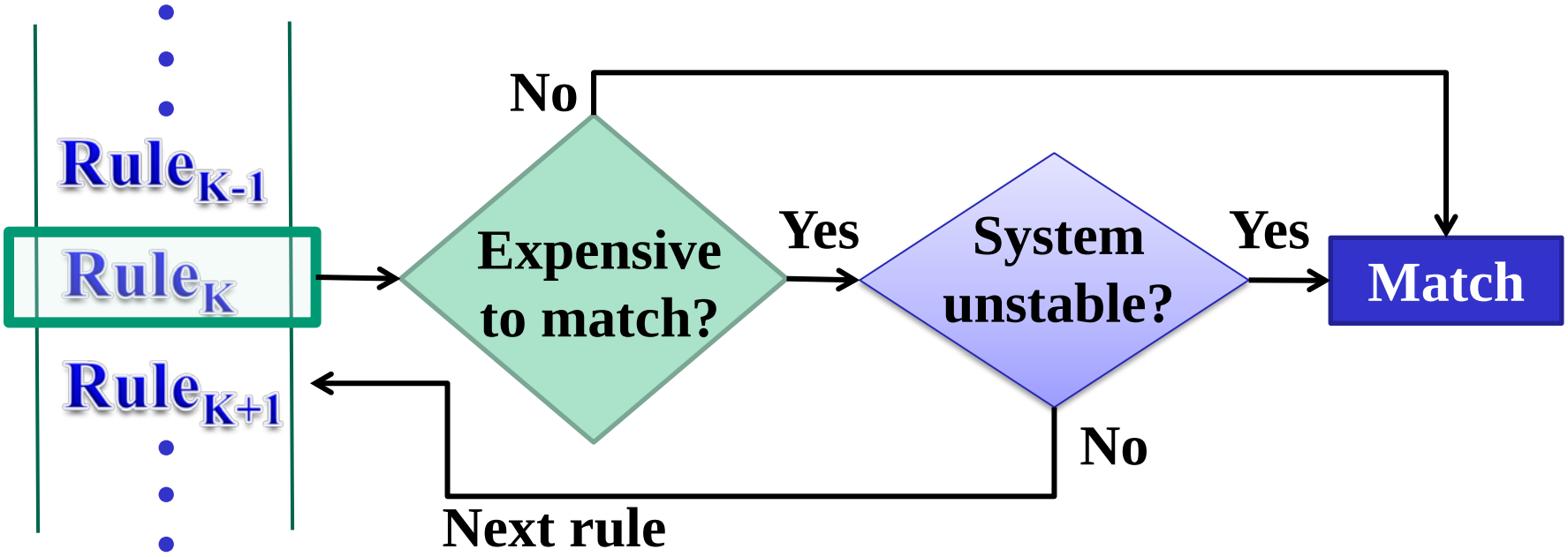
	Virtual Memory	RAM
Monitor	282.27	25.53
Pinpoint-PCFG	933.56	696.06

- Monitor doesn't rely in large data structures
- PCFG in Pinpoint has high **space** and **time** complexity
  - $O(RL^2)$ and $O(L^3)$

  R: number of rules in the grammar

  L: size of a web interaction
- Pinpoint thrashes due to high memory requirements

Efficient Rule Matching



- Selectively match computationally expensive rules
  - Expensive rules don't have to be matched all the time
- Rules are matched only if instability is present

Efficient Rule Matching Example: *Detecting Memory Leak*

- Efficiently detect memory leak in Apache web server
  - Memory leak injected probabilistically with web requests
- Expensive ARIMA-based rule to detect abnormal memory usage
  - Average matching latency reduced

Rule Matching Criteria	Memory Leak Detected	Average Matching Latency (msec.)
Always matched	yes	19.283
$\sigma \geq 0.5$	yes	7.115
$\sigma \geq 1.0$	no	1.25

Concluding Remarks

- Contributions:
  - **Sampling** used to **scale** stateful detection system under high-rate of messages
  - **Intelligent Sampling** reduces non-determinism caused by sampling
  - **HMM-approach** handles incorrect messages
  - Techniques can be applied to any stateful detection system
  - Monitor performs better than other approaches

- Future Work:
  - **Efficient Rule Matching** technique will be extended
  - Sampling only sequences of messages that lead to errors
  - Automatic generation of rules from traces