Distributed Diagnosis of Failures in a Three Tier E-Commerce System

Gunjan Khanna, Ignacio Laguna, Fahad A. Arshad, and Saurabh Bagchi
Dependable Computing Systems Lab (DCSL)
School of Electrical and Computer Engineering
Purdue University

Motivation

- Connected society of today has come to rely heavily on distributed computer infrastructure
  - ATM networks, Airline reservation systems, distributed internet services
- Increased reliance on Internet services supported by multi-tier applications
  - Cost of downtimes of these systems can run into several millions of dollars
    - Financial brokerage firms have a downtime cost $6.2M/hr (Source: IDC, 2005)
- Need a scalable real-time diagnosis system for determining root cause of a failure
- Identify the faulty elements so that fast recovery is possible (low MTTR), giving high availability

Challenges in Diagnosis for E-Commerce Systems

- **Diagnosis**: Protocol to determine the component that originated the failure
- There is complex interaction among components in three tier applications
  - Components belong to one of three layers - web, application tier and database
  - Not all interactions can be enumerated *a priori*
  - Large number of concurrent users
  - Rate of interactions is high
- Errors can remain undetected for an arbitrary length of time
  - An error can propagate from one component to another and finally manifest itself as a failure
  - High error propagation rate due to high rate of interactions

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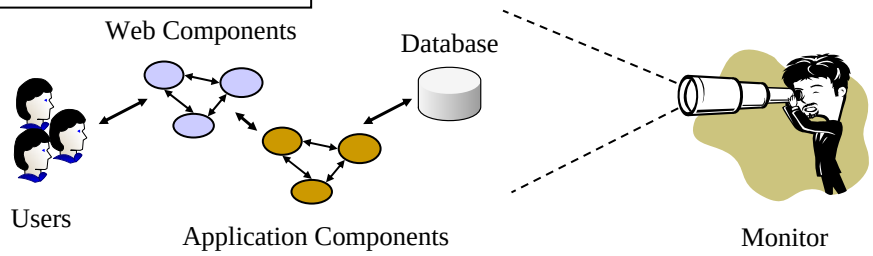
Solution Approach: Monitor

SRDS '04, TDSC '06, TDSC '07



- **Non intrusive:** observe messages exchanged and estimate application state transitions
- **Anomaly based:** match against a rule base
- **Online:** fast detection and diagnosis
- Treat application entities (or components) as Black-box

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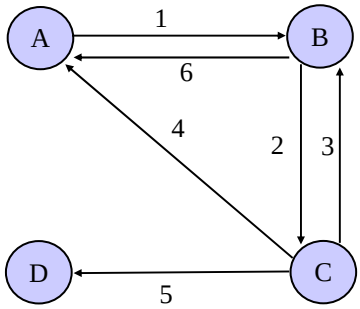
Tracking Causal Dependencies

- Messages between the components are used to build a *Casual Graph* (CG)
- Vertices are components, and edges are interactions between components
- Intuition: A message interaction can be used to propagate an error

Components interacting by message passing

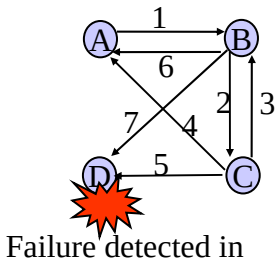


Message ID	Logical Time
1	L1
2	L2
3	L3

Aggregate Graph

- We bound the size of the Casual Graph
  - Unbounded CG would lead to long delays in traversing the CG during diagnosis leading to high latency
  - However, complete purging of the information in the *CG* can cause inaccuracies during the diagnosis process
- We aggregate the state information in the Casual Graph at specified time points and store it in an *Aggregate Graph* (*AG*)
- The AG contains aggregate information about the protocol behavior averaged over the past
  - *AG* is similar to *CG* in the structure (a node represents a component and a link represents a communication channel)
  - AG maintains historical information about failure behavior of components and links

Diagnosis in the Presence of Failures



Failure detected in Component D

Diagnosis algorithm triggered

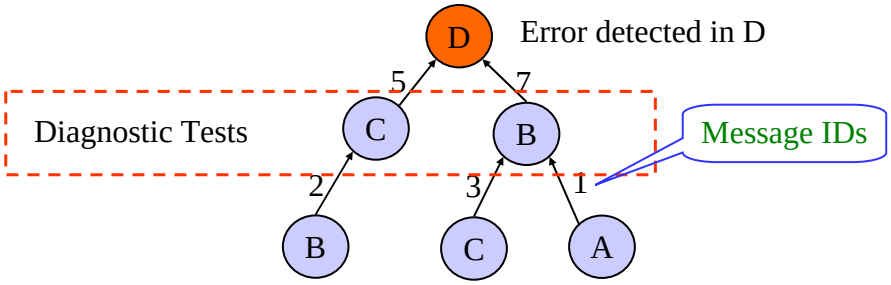
Monitor

Which components have interacted with D previously?

- When a failure is detected in a node n_f, Monitor checks which other components have interacted with n_f in the CG
  - Bounded search space due to the bounded nature of CG
- The diagnosis algorithm is then triggered

Diagnosis Tree

- A tree rooted at the n_f (where the failure is detected) is built from CG: *Diagnosis Tree*
  - Nodes which have directly sent a message to n_f are at depth 1
  - Nodes which have directly sent a message to a node at depth h are at depth $h+1$



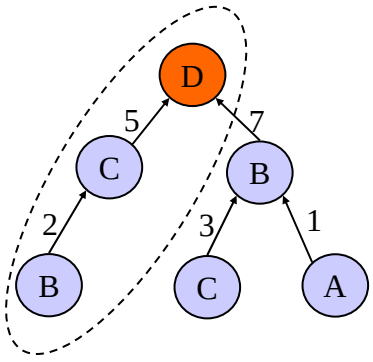
Diagnostic Tests

- Diagnostic tests are specific to the component and its state
  - The state is as deduced by the Monitor
  - Example: After receiving 10 KB of data, did the component send an acknowledgement?
  - Example: After receiving a database update due to a transaction, did the update complete within 5 seconds?
- No active probing of the components with tests
  - State of the component may have changed during the error propagation
  - Probing introduces additional stress on the components when failures are already occurring
- Tests may not be perfect
  - They are probabilistic in nature

PPEP: Path Probability of Error Propagation

- ***Definition: PPEP(n_i, n_j),***
  the probability of node n_i *being faulty and causing this error to propagate on the path from* n_i *to* n_j*, leading to a failure at* n_j

- PPEP depends on
  - ***Node Reliability*** of the node which is possibly faulty
  - ***Link Reliability*** of links on path
  - ***Error Masking capability*** of intermediate nodes on path



Example:
PPEP(B, D)

Node Reliability

- **Node Reliability** *(n_r)*: quantitative measure of the reliability of the component
- It is obtained by running the diagnostic tests on the states of the components
  - Coverage of the component *c(n) = #tests that succeeded/#tests*
- PPEP is inversely proportional to node reliability
  - More reliable node, therefore less likelihood of originating the chain of errors

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Link Reliability

- **Link Reliability** $lr_{(i,j)}$: quantitative measure of the reliability of the network link between two components
- $lr_{(i,j)}$ = number of received messages in receiver n_j / number of sent messages in sender n_i
- PPEP is proportional to link reliability
  - Reliable links increase probability of the path being used for propagating errors

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Error Masking Capability (EMC)

- **Error Masking Capability** *(e_m):* quantitative measure of the ability of a node to mask an error and not propagate it to the subsequent node on the path
- *EMC* of a component depends on the type of error, e.g., syntactical or semantic errors
  - A node may be able to mask all "off by one" errors but not an error which leads to a higher rate stream
- PPEP is inversely proportional to the *EMC* of node in the path
  - The intermediate nodes are less likely to have propagated the error to the root node

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Calculating PPEP for a Path

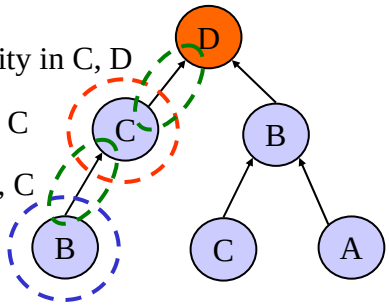
- Example: Calculate PPEP from B to D

$lr_{(C, D)}$: Calculate link reliability in C, D

e_m(C): Calculate EMC in C

$lr_{(B, C)}$: Calculate link reliability in B, C

n_r(B): Calculate node reliability of B



$$PPEP(B, D) = (1- n_r(B)) \bullet lr_{(B, C)} \bullet (1- e_m(C)) \bullet lr_{(C, D)}$$

- For a general path,

$$PPEP(n_1, n_k) = (1-n_r(n_1))\cdot lr_{(1,2)}\cdot(1- e_m(n_2))\cdot lr_{(2,3)}\ldots \cdot lr_{(i,i+1)}\cdot(1- e_m(n_{i+1}))\cdot lr_{(i+1,i+2)}\ldots (1- e_m(n_{k-1}))\cdot lr_{(k-1,k)}$$

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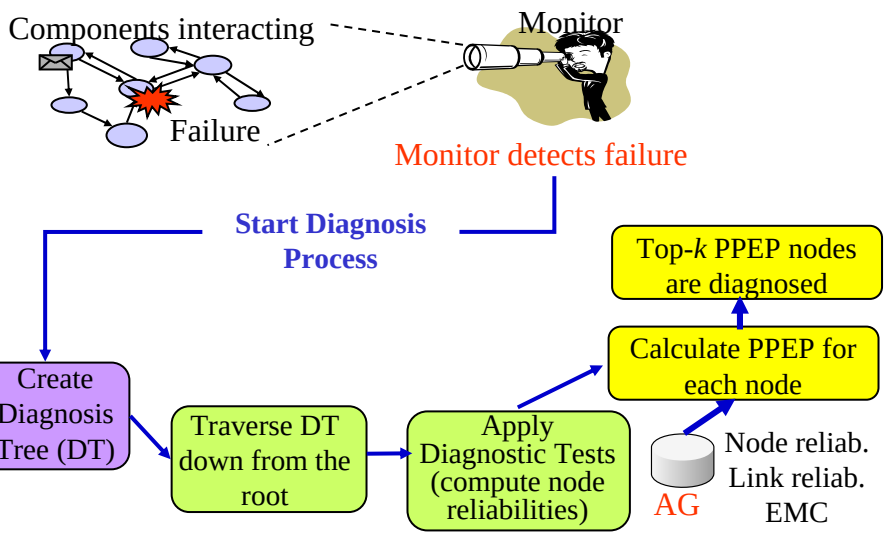
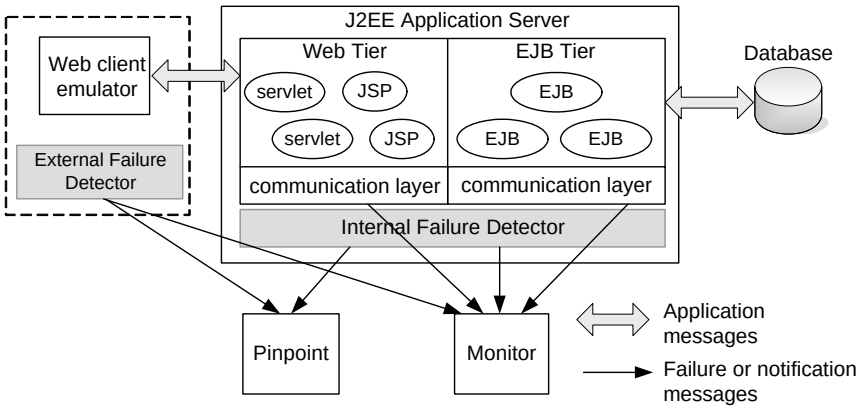
Overall Flow of the Diagnosis Process



Experimental Testbed

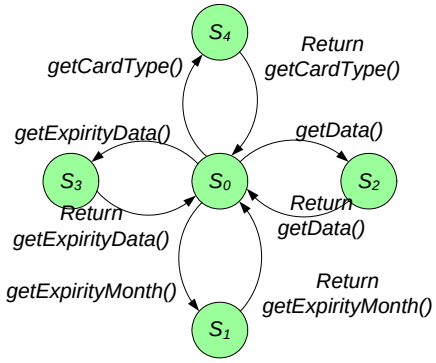
- Application: Pet Store (version 1.4) from Sun Microsystems
- Pet Store runs on top of the JBoss application server with MySQL database as the back-end providing an example of a 3-tier environment
- A web client emulator which generates client transactions based on sample traces (written in Perl)
- For the mix of client transactions, we mimic the TPC-WIPSo distribution with equal percentage of browse and buy interactions
  - A *web interaction* is a complete cycle of communication between the client emulator and the application
  - A *transaction* is a sequence of web interactions. Example: *Welcome page → Search → View Item details*

Logical Topology



Monitor Configuration

- The Monitor is provided an input of state transition diagrams for the verified components and causal tests



Example Rules

S0 getData 1 S2 return getData1 1

S0 getExpiryMonth 1 S1 return getExpiryMonth 1

S0 getExpiryData 1 S3 return getExpiryData 1 1

Comparison with Pinpoint

- Pinpoint (Chen et al., DSN '02, NSDI '04) represents a recent state-of-the-art black-box diagnosis system
  - Well explained and demonstrated on an open source application
  - We implement the Pinpoint algorithm (online) for comparison with the Monitor's diagnosis approach
- Summary of Pinpoint algorithm:
  - Pinpoint tracks which components have been touched by a particular transaction
  - Determine which transaction has failed
  - By a clustering algorithm (UPGMA), Pinpoint correlates the failures of transactions to the components that are most likely to be the cause of the failure

Performance Metrics

- *Accuracy*: a result is accurate when all components causing a fault are correctly identified
  - Example, if two components, *A* and *B*, are interacting to cause a failure, identifying both would be accurate
  - Identifying only one or neither would not be accurate
  - Example: if predicted fault set is {*A*, *B*, *C*, *D*, *E*}, but faults were in components {*A*, *B*} → accuracy still 100%
- *Precision*: penalizes a system for diagnosing a superset
  - Precision is the ratio of the number of faulty components to the total number of entities in the predicted fault set
  - Above example: precision = 40%
  - Components {*C*, *D*, *E*} are false positives

Fault Injection on Different Components

- We use 1-component, 2-component and 3-component triggers
- *1-component trigger*: every time the target component is touched by a transaction, the fault in injected in that component
- *2-component trigger*: a sequence of 2-components is determined and during a transaction, the last component in the transaction is injected
  - This mimics an interaction fault between two components
  - Both components should be flagged as faulty
- *3-component* fault is defined similarly as in *2-component*

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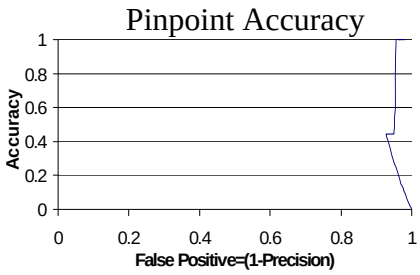
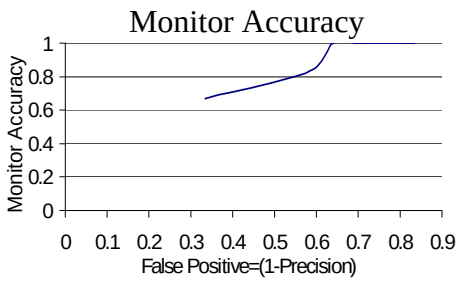
Results for a 1-Component Fault Injection





- Both can achieve high accuracy but Pinpoint suffers from high false positive rates
- In Pinpoint, two different accuracy values can be achieved since a given precision value is achieved for two different cluster sizes
- The latency of detection in our system is very low
  - Thus, the faulty component is often at the root of the *DT* in the Monitor.

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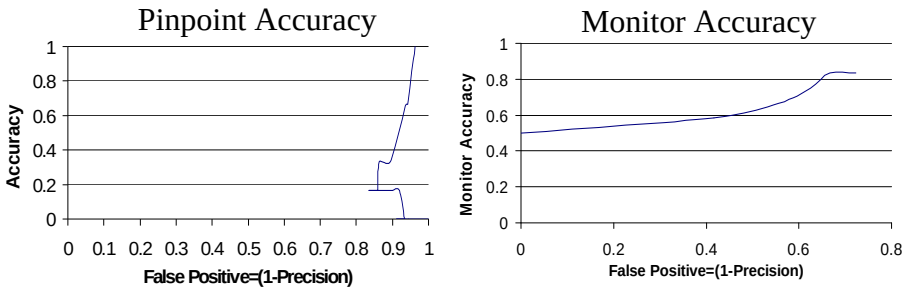
Results for a 2-Component Fault Injection



- Performance of the Monitor declines and Pinpoint improves from the single component fault
  - Monitor still outperforms Pinpoint
- Monitor gets less opportunity for refining the parameter values ⇒ the *PPEP* calculation is not as accurate as for the single component faults

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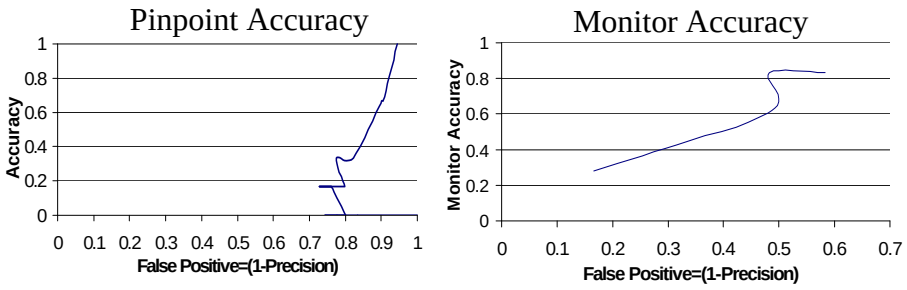
Results for a 3-Component Fault Injection



- Performance of the Monitor declines and Pinpoint improves from the single and two component faults
- Monitor still outperforms Pinpoint
- Pinpoint maximum average precision value ~ 27%
  - Attributed to the fact that more number of components causes selected transactions to fail ⇒ better performance by the clustering algorithm
- Monitor declines because of the same reason as in 2-component faults

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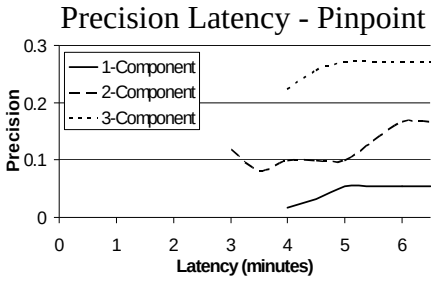
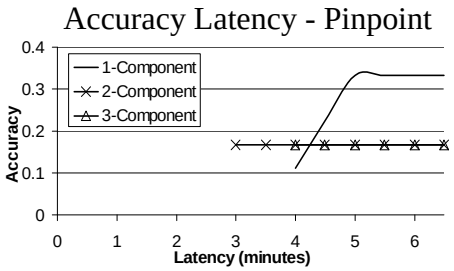
Latency Comparison





- The Monitor has an average latency of 58.32 ms with a variance of 14.35 ms
- After 3.5 minutes the accuracy and precision of Pinpoint increase with latency
- Pinpoint takes as input the transactions and corresponding failure status every 30 seconds during a round
  - Pinpoint runs the diagnosis for each of these snapshots taken at 30 second intervals

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Related Work

- **White and Black box systems**
  - White box where the system is observable and, optionally, controllable. Black box where the system is neither
  - "Alert correlation in a cooperative intrusion detection framework," IEEE Symp. on Security and Privacy '02
- **Debugging in distributed applications**
  - Work in providing tools for debugging problems in distributed applications
  - Performance problems: "Performance debugging for distributed systems of black boxes," SOSP '03
  - Misconfigurations: "PeerPressure" ACM SIGMETRICS '04
- **Network diagnosis**
  - Root cause analysis of network faults models
  - "Shrink," ACM SIGCOMM '05
  - "Correlating instrumentation data to system states," OSDI '04
- **Automated diagnosis in COTS systems**
  - Automated diagnosis for black-box distributed COTS components
  - "Automatic Model-Driven Recovery in Distributed Systems," SRDS '05

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Conclusions

- We presented an online diagnosis system called Monitor for arbitrary failures in distributed applications
- Diagnosis can be performed online with low latency
- Monitor's probabilistic diagnosis outperforms Pinpoint by achieving higher accuracy for the same precision values
- Complex interaction of components in e-commerce system make accurate diagnosis challenging
- Clustering algorithms like the used in Pinpoint have high dependency on the complexity of the application
  - Need for many distinguishable transactions to achieve high accuracy
  - Transactions must touch almost all the components
- Future Work: How do we estimate diagnosis parameter values more accurately?

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Backup Slides

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Detectors and Injected Failures

- Internal and an external failure detectors are created to provide failure status of transactions to Pinpoint and Monitor
- Faults are injected into Pet Store application components: Servlets and EJBs
- Four different kinds of fault injection:
  - (1) Declared exceptions
  - (2) Undeclared exceptions
  - (3) Endless calls
  - (4) Null call
- The internal detector is more likely to detect the declared and undeclared exceptions, and the null calls
- The external detector is more likely to detect the endless call

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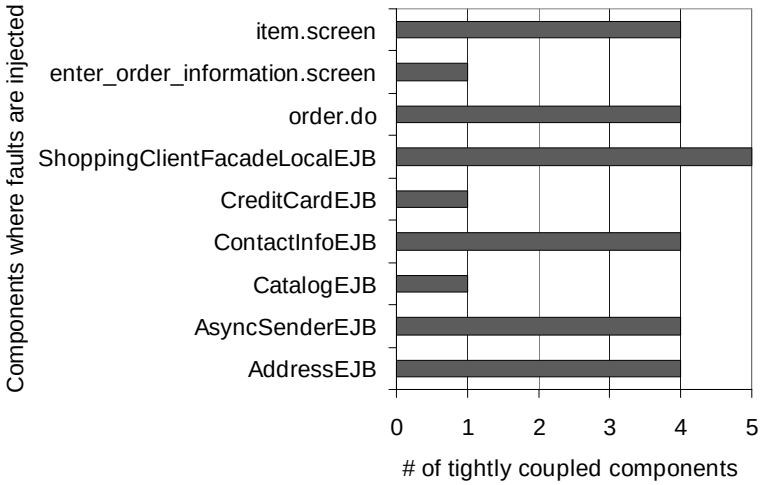
Number of tightly coupled components for Pet Store



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