Profiling and diagnosing large-scale decentralized systems

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Why focus on P2P systems?

- **There are a few real ones**
  - file trading, backup, IM
- **Look a *lot* like other decentralized wide-area sys.**
  - Grid, sensor networks, mobile ad-hoc networks, …
- **Look a *little* like all wide-area systems**
  - geog. dist. Internet services, content distribution. networks, federated web services, *@home, DNS, BGP, …
- **Good platform for prototyping services that will eventually be deployed on a large cluster (Brewer)**
- **P2P principles seeping into other types of large systems (corporate networks, clusters, …)**
  - self-configuration/healing/optimization
  - decentralized control
- **Large variability (in configurations, software versions, …) justifies a rich fault model**

Why focus on P2P systems? (cont.)

- This is NOT about the DHT abstraction
- DHT research code just happens to be the best platform for doing wide-area networked systems research right now

What's the problem?

- **Existing data collection/query and fault injection techniques not sufficiently robust and scalable for very large systems in constant flux**
  - ⇒**goal**: enable cross-component decentralized sys. profiling
  - – decentralized data collection
  - – decentralized querying
  - – online data collection, aggregation, analysis
- **Detecting and diagnosing problems is hard**
  - ⇒**goal**: use profile/benchmark data collection/analysis infrastructure to detect/diagnose problems ($<$ TTD/TTR)
  - ⇒**observation**: abnormal component metrics (may) indicate an application or infrastructure problem
  - – distinguishing normal from abnormal per-component and per-request statistics (anomaly detection)

Benchmark metrics

- **Visible at user ⟷ application interface**
  - latency, throughput, precision, recall
- **Visible at application ⟷ routing layer interface**
  - latency and throughput to {find object's owner, route msg to owner, read/write object}, latency to join/depart net
- **Cracking open the black box**
  - per-component and per-request consumption of CPU, memory, net resources; # of requests component handles; degree of load balance; # of replicas of data item
- **Recovery time, degradation during recovery**
  - recovery time broken into Π\{detect, diagnose, repair\}
- **Philosophy: collect fine-grained events, aggregate later as needed**

	per-component	across all components
per-request	collect	aggregate
across all requests	aggregate	aggregate

Querying the data: simple example

(SQL used for illustration purposes only)

app-level request sends

KS

nodeID	req id	time
x1	1	5:0.18
x1	2	10:0.01
x1	…	…

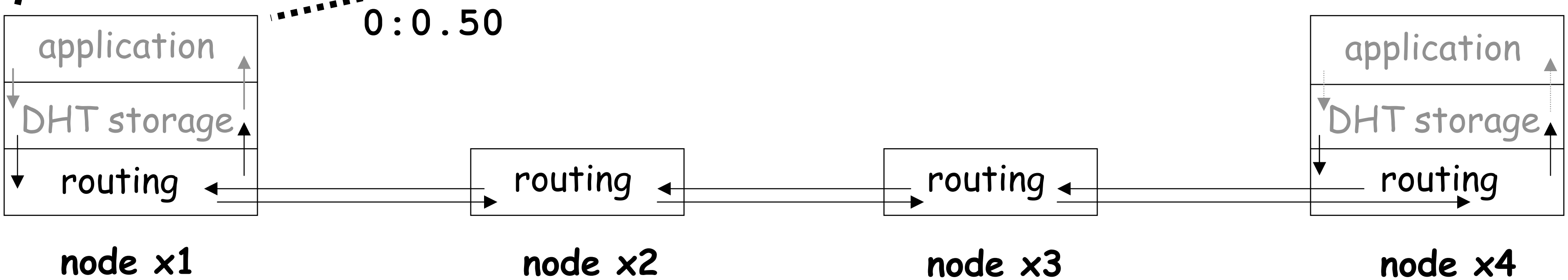
app-level response receives

KR

nodeID	req id	time
x1	1	5:0.28
x1	2	10:0.91
x1	…	…

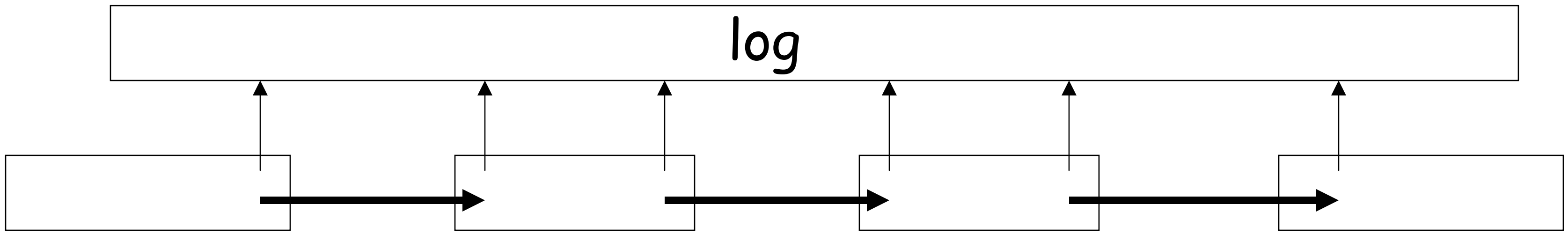
```
SELECT avg(KR.time-KS.time)
FROM   KR, KS
WHERE  KR.id = KS.id AND
       nodeID = x1
```

0:0.50



Schema motivation

- **Popular programming model is stateless stages/components connected by message queues**
  - "event-driven" (*e.g.*, SEDA), "component-based," "async"
- **Idea: make the monitoring system match**
  - record activity one component does for one request
    - » starting event, ending event
- **Moves work from collection to query time**
  - this is good: slower queries are OK if means monitoring won't degrade the application



Monitoring "schema"
(tuple per send/rcv event)

data item	bytes
operation type (send/receive)	1
my node id	4
my component type	4
my component id	8
global request id	16
component sequence #	4
request type	4
time msg sent/received	8
msg size	8
arguments	> 4
return value	4
message contents	256

(send table only)

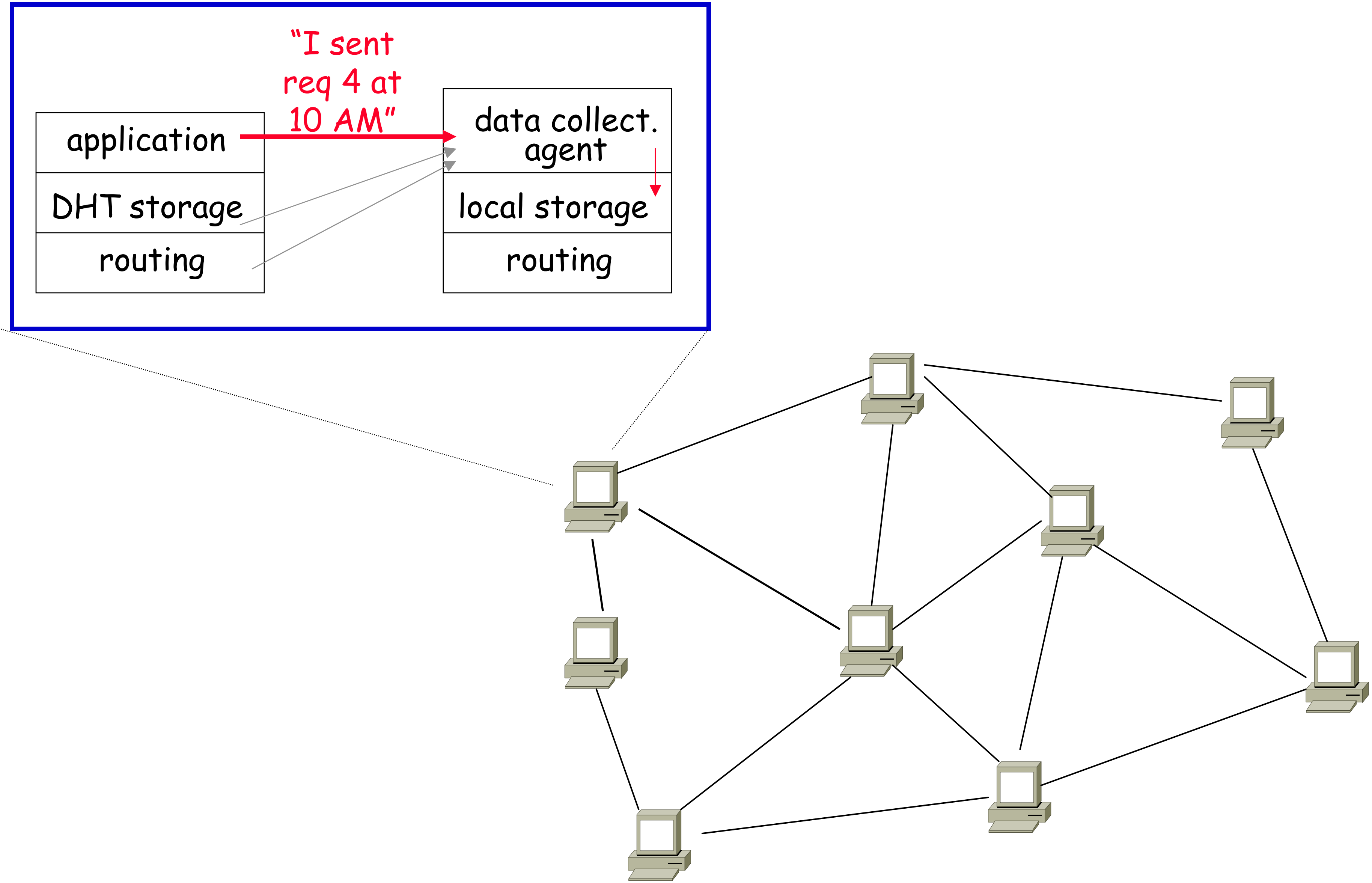
data item	bytes
peer node id	4
peer component id	4
memory consumed this msg	4
CPU consumed this msg	4
disk consumed this msg	4
net consumed this msg	4

What is data rate? [10k-node system, 5k req/sec]

» ~28 msgs/req * 5000 req/sec = 140,000 tuples/sec (=>14tps/node)

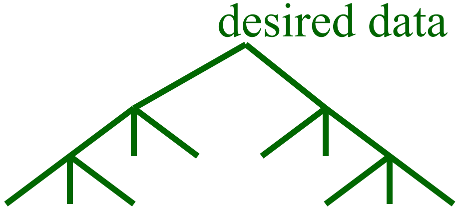
» ~50B/tuple * 140,000 tuples/sec = ~53 Mb/sec (=>5.5 Kbps/node)

Decentralized metric collection



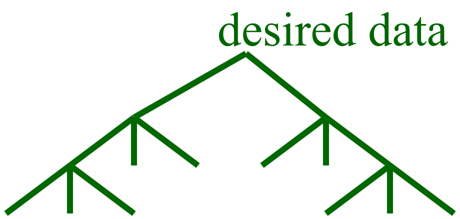
Querying the data

- **Version 0 (currently implemented)**
  - log events to local file
  - fetch everything to querying node for analysis (scp)
- **Version 1 (use overlay, request data items)**
  - log events to local store (file, db4, …)
  - querying node requests **data items** for local processing using "sensor" interface
  - **key** could be query ID, component ID, both, other…
  - overlay buys you self-configuration, fault-tolerance, network locality, caching
  - two modes
    - » **pull based** (periodically poll)
    - » **push based** (querying node registers continuously-running proxy on queried node(s))



Querying the data, cont.

- **Version 2 (use overlay, request predicate results)**
  - log events to local store (file, db4, …)
  - querying node requests **predicate results** from end-nodes
    - » queried node can filter/sample, aggregate, …, before send results
    - » allows in-network filtering, aggregation/sampling, trigger
    - » can use to turn on/off collecting specific metrics, nodes, or components
    - » SQL translation: push SELECT and WHERE clauses
  - two modes
    - » **pull based**
    - » **push based**



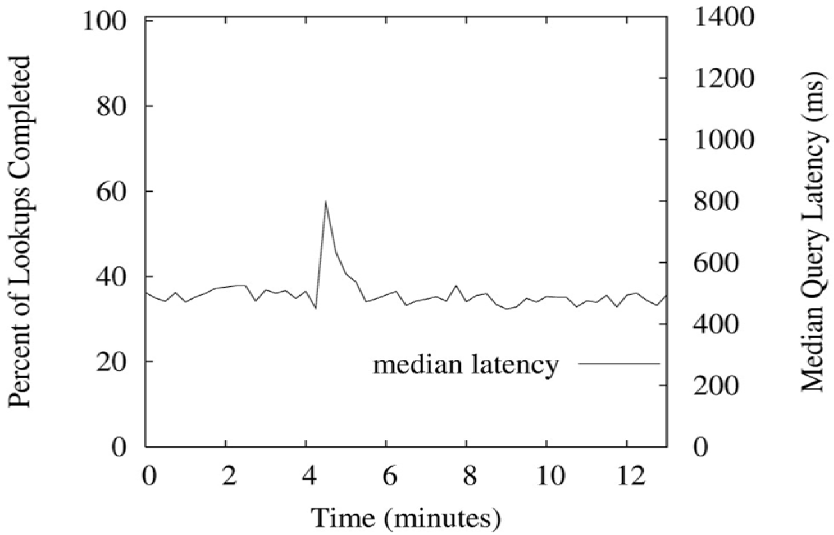
- **Goal is to exploit domain-specific knowledge**

What's the problem?

- Existing data collection/query and fault injection techniques not sufficiently robust and scalable for very large systems in constant flux
  - ⇒**goal**: enable cross-component decentralized sys. profiling
  - decentralized data collection
  - decentralized querying
  - online data collection, aggregation, analysis

- **Detecting and diagnosing problems is hard**
  - ⇒**goal**: use profile/benchmark data collection/analysis infrastructure to detect/diagnose problems (< TTD/TTR)
  - ⇒**observation**: abnormal component metrics (may) indicate an application or infrastructure problem
  - distinguishing normal from abnormal per-component and per-request statistics (anomaly detection)

What the operator/developer wants to know



1. **Is there a problem?**
   - s/w correctness bug, performance bug, recovery bug, hardware failure, overload, configuration problem, …
2. **If so, what is the cause of the problem?**

Currently: **human involved in both**

Future: **automate, and help human with, both**

Vision: automatic fault detection

- **Continuously-running queries that generate alert when exceptional conditions are met**
  - **example**: avg application response time during last minute > 1.1 * avg response time during last 10 minutes

[now = 11:0.0]

```
SELECT "alert" AS result WHERE
(SELECT avg(KR.time-KS.time)
FROM KR[Range 1 Minute], KS
WHERE KR.id=KS.id) > 1.1 *
(SELECT avg(KR.time-KS.time)
FROM KR[Range 10 Minute], KS
WHERE KR.id=KS.id)
```

0:0.90 > 1.1 * 0:0.50 ?   *ALERT!*

app-level request sends

KS

req id	time
1	5:0.18
2	10:0.01
…	…

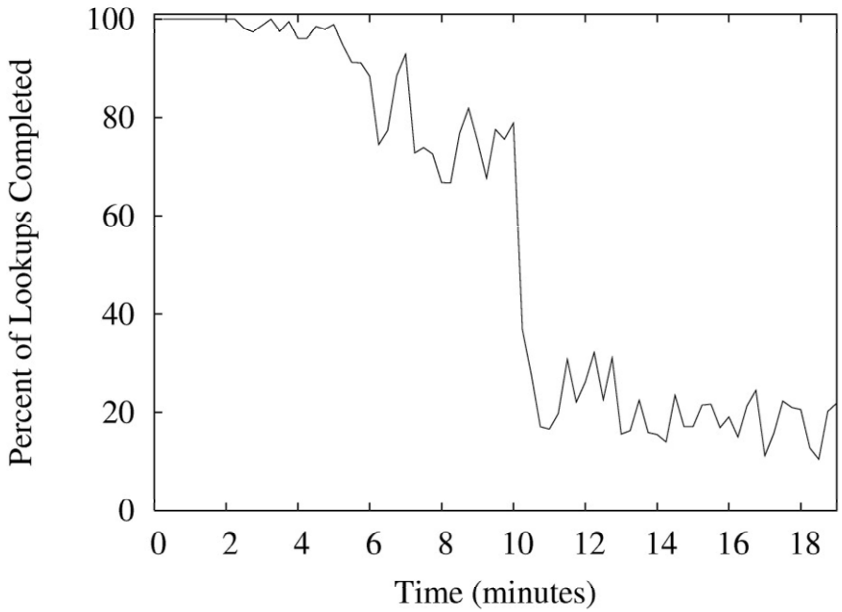
app-level response receives

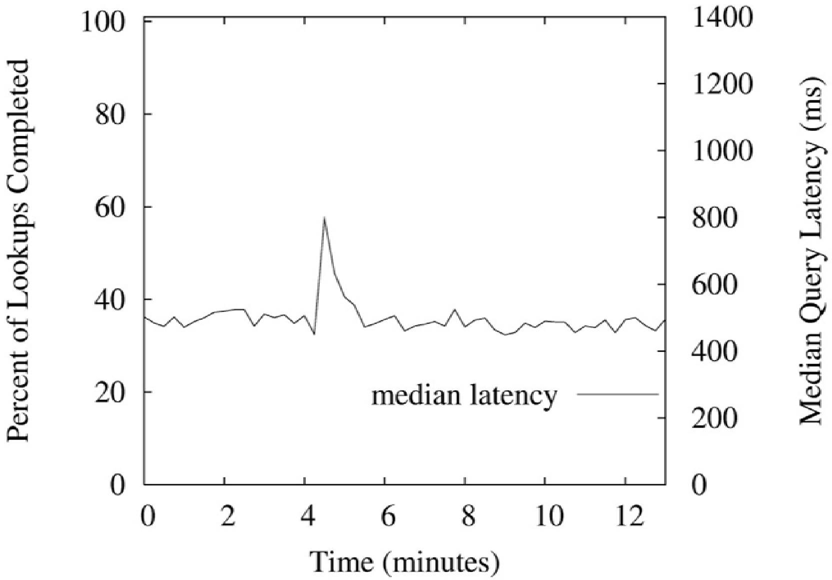
KR

req id	time
1	5:0.28
2	10:0.91
…	…

Status: essentially implemented (for a few metrics)

- Built on top of event logging + data collection infrastructure used for the benchmarks
- Not yet implemented: threshholding
  - currently just collects and graphs the data
  - human generates alert using eyeballs and brain





Vision: automatic diagnosis (1)

- Find request that experienced highest latency during past minute

[now = 11:0.0]

KS

req id	time
1	5:0.18
2	10:0.01
...	...

KR

req id	time
1	5:0.28
2	10:0.91
...	...

```
SELECT KR.time-KS.time, KR.id as theid
FROM KR[Range 1 Minute], KS[Range 1 Minute]
WHERE KR.id=KS.id AND KR.time-KS.time = (
SELECT max(KR.time-KS.time)
FROM KR[Range 1 Minute], KS[Range 1 Minute]
WHERE KR.id = KS.id)
```

0:0.90, theid = 2

[we will investigate this request on the next slide]

Vision: automatic diagnosis (2)

- **How long did it take that message to get from hop to hop in the overlay?**

IS, IR tables: decentralized routing layer sends/receives

IS (node A)

req id	time	me	nexthop
2	10:0.05	A	B
11	…	A	D
…	…	A	…

IR (node A)

req id	time	me
2	…	A
11	…	A
…	…	A

IS (node B)

req id	time	me	nexthop
2	…	B	C
13	…	B	E
…	…	B	…

IR (node B)

req id	time	me
2	10:0.85	B
23	…	B
…	…	B

```
SELECT IR.time-IS.time as latency, IS.me as sender, IR.me as receiver
WHERE  IS.nexthop=IR.me AND IS.id = 2 AND IR.id = 2
```

latency = …, sender = …, receiver = A

latency = 0.80, sender = A, receiver = B

latency = …, sender = B, receiver = …

Status: manual "overlay traceroute"

- **Simple tool to answer previous question**
  - "How long did it take that message to get from hop to hop in the overlay?"
- **Built on top of event logging+data collection infrastructure used for the benchmarks**
- **Only one metric: overlay hop-to-hop latency**
- **Synchronizes clocks (currently out-of-band)**
- **Operates passively**
- **No fault injection experiments yet; coming soon**

optype	reporting_node	request_id	report_time	diff
inject	169.229.50.219	3@169.229.50.219	1054576732997161	
forward	169.229.50.223	3@169.229.50.219	1054576732998725	1564
forward	169.229.50.213	3@169.229.50.219	1054576733008831	10106
forward	169.229.50.226	3@:169.229.50.219	1054576733021493	12662
deliver	169.229.50.214	3@169.229.50.219	1054576733023786	2293

Building and using behavioral profiles

- **Benchmarks measure behavioral profile for fixed w/load**
- **Goal is to automate problem detection/diagnosis**
  - too much data for a human to do it manually
- **Version 0 (human builds and applies model)**
  - human detects and diagnosis problems
    - » watch aggregate benchmark metrics, drill down w/ traceroute
- **Version 1 (human builds, system applies model)**
  - "tell me when condition X is met"
  - human defines alarm conditions, system detects when met
- **Version 2 (system builds, system applies model)**
  - "tell me when something bad happens, and why/where"
  - system defines alarm conditions and detects when met (anomaly detection)
- **Keep human in loop**
  - big red button
  - make model and metrics understandable for human

Questions for current/future work

- **Explore techniques for failure inference/diagnosis**
  - leverage statistical techniques from Magpie and intrusion detection
- **Applicability of statistical techniques from real Internet services to wide-area (need data!!!)**
- **What is a component?**
  - profile Java object time spent and data accesses
    - » had undergrads working on this this semester
- **Robustness to system flux**
- **Minimizing code changes to profiled systems**
- **Handling schema evolution and application-specific metrics**
  - XML suggested yesterday
- **Using these techniques for intrusion detection**

Related work

- **Closely related to Magpie (MSR Cambridge)**
  - embrace and extend
    - » larger, geographically distributed systems
    - » explore more models and techniques for change detection
- **Part 2 has some relationship to Pinpoint**
  - but larger, geographically distributed systems
  - adds *latency profiles*
  - adds *per-component* metrics
  - means very different data collection techniques and types of analyses
- **Various distributed query processors**
- **Remote monitoring of instrumented software**

Conclusion and status

- **Existing data collection/analysis techniques not sufficiently robust and scalable for very large systems in constant flux**
  - **currently**: collect data in per-node logs, aggregate on central node for analysis
  - **future**: decentralized storage, query, analysis
- **Detecting and diagnosing problems is hard**
  - **currently**: collect *aggregate metrics* (latency, consistency, bandwidth consumed) and *per-request metrics* (hop-to-hop overlay latencies)
  - **future:** online data collection, aggregation, analysis; automatically distinguish normal from abnormal component and request statistics (anomaly detection)
- **Initial application targets**
  - DHTs: Bamboo, Tapestry
  - applications: Seagull, (Palimpsest), other suggestions??