Rake: Semantics Assisted Network-based Tracing Framework

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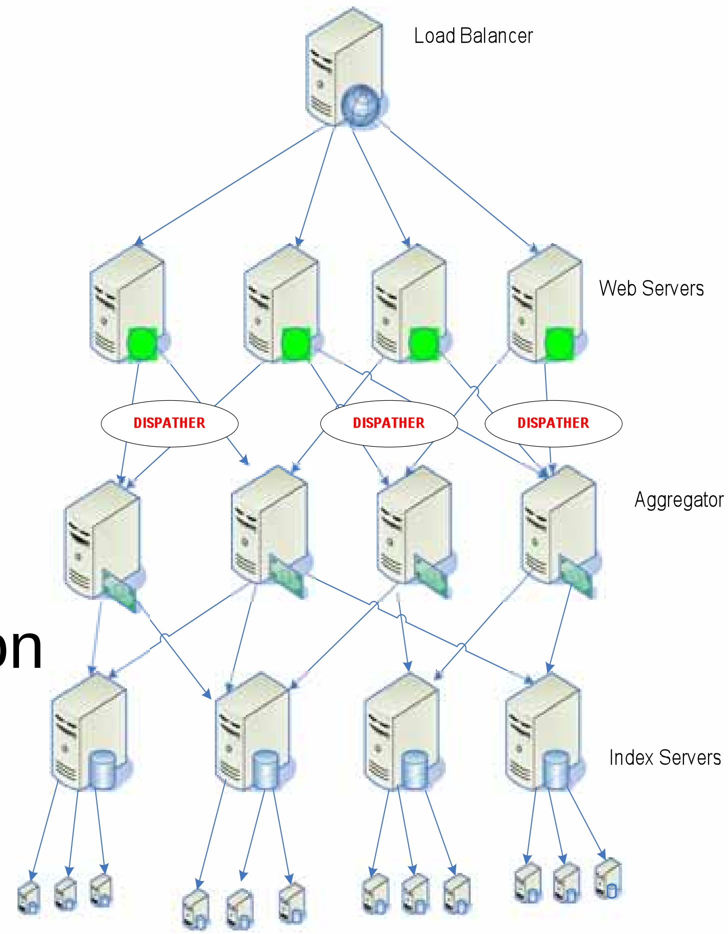
Motivation

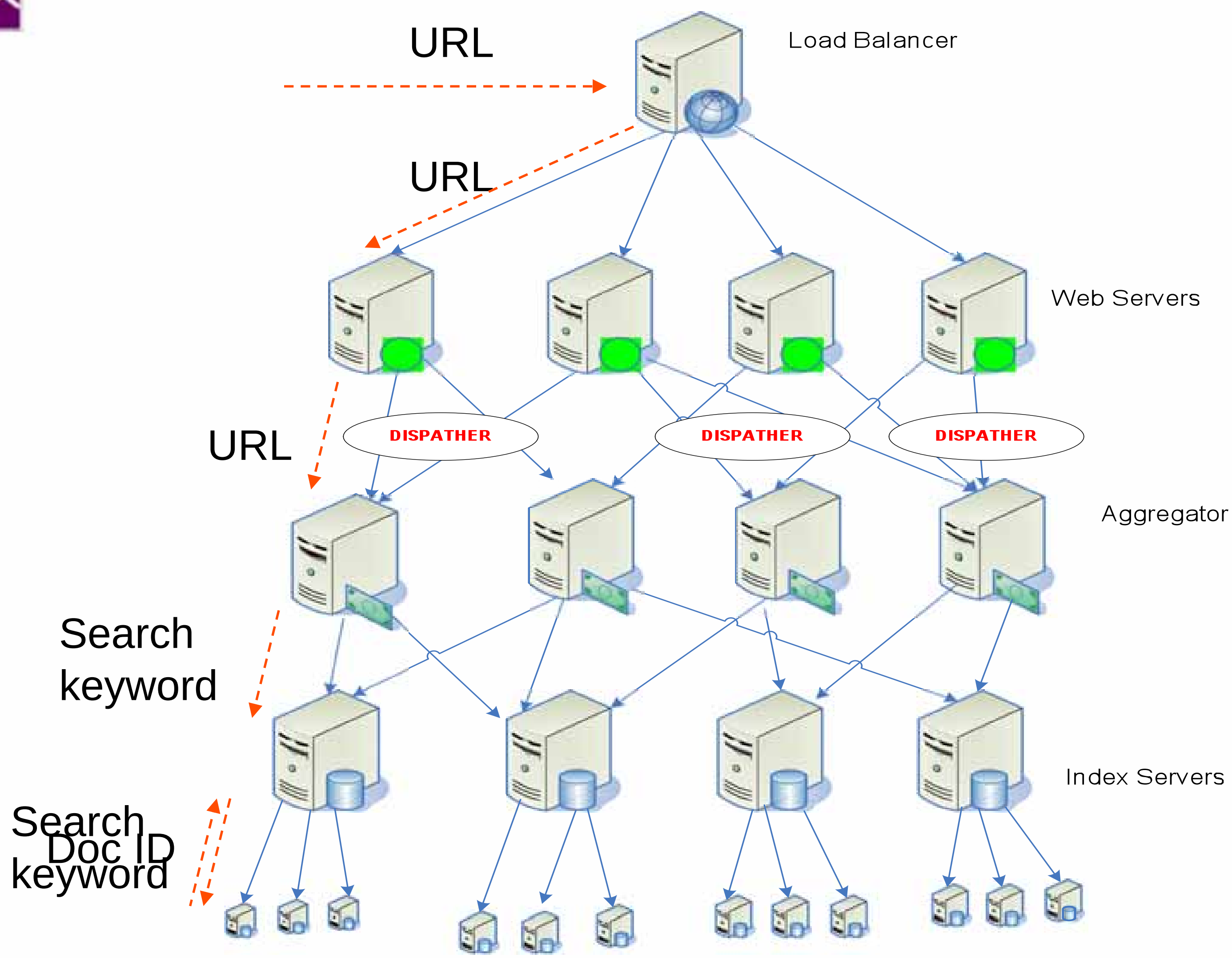
- Large distributed systems involve thousands of or even 100s of thousands of nodes
  - E.g. search system, CDN
- Host-based monitoring cannot infer the performance or detect bugs
  - Hard to translate OS-level info (such as CPU load) into application performance
  - App log may not be enough
  - Hard to collect all the logs
- Task-based approach adopted in many diagnosis systems
  - WAP5, Magpie, Sherlock



Task-based Approaches

- The Critical Problem – Message Linking
  - Link the messages in a task together into a path or tree

Example of Message Linking in Search System

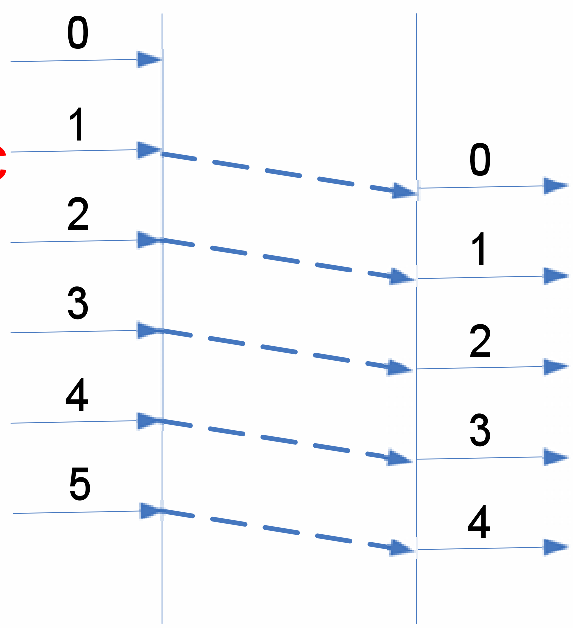


Task-based Approaches

- The Critical Problem – Message Linking
  - Link the messages in a task together into a path or tree
- Challenges
  - Accuracy
  - Non-invasiveness
  - Scalability to large computing platforms
  - Applicability to a large number of applications

Existing Approaches

- Black-box approaches
  - Do not need to instrument the application or to understand its internal structure or semantics
  - Time correlation to link messages
    - Project 5, WAP5, Sherlock
  - Rely on time Correlation
  - Accuracy affected by cross traffic



Existing Approaches

- White-box approaches
  - Extracts application-level data and requires instrumenting the application and possibly understanding the application's source codes
  - Insert a unique ID into messages in a task
    - X-Trace, Pinpoint
  - Invasive due to source code modification

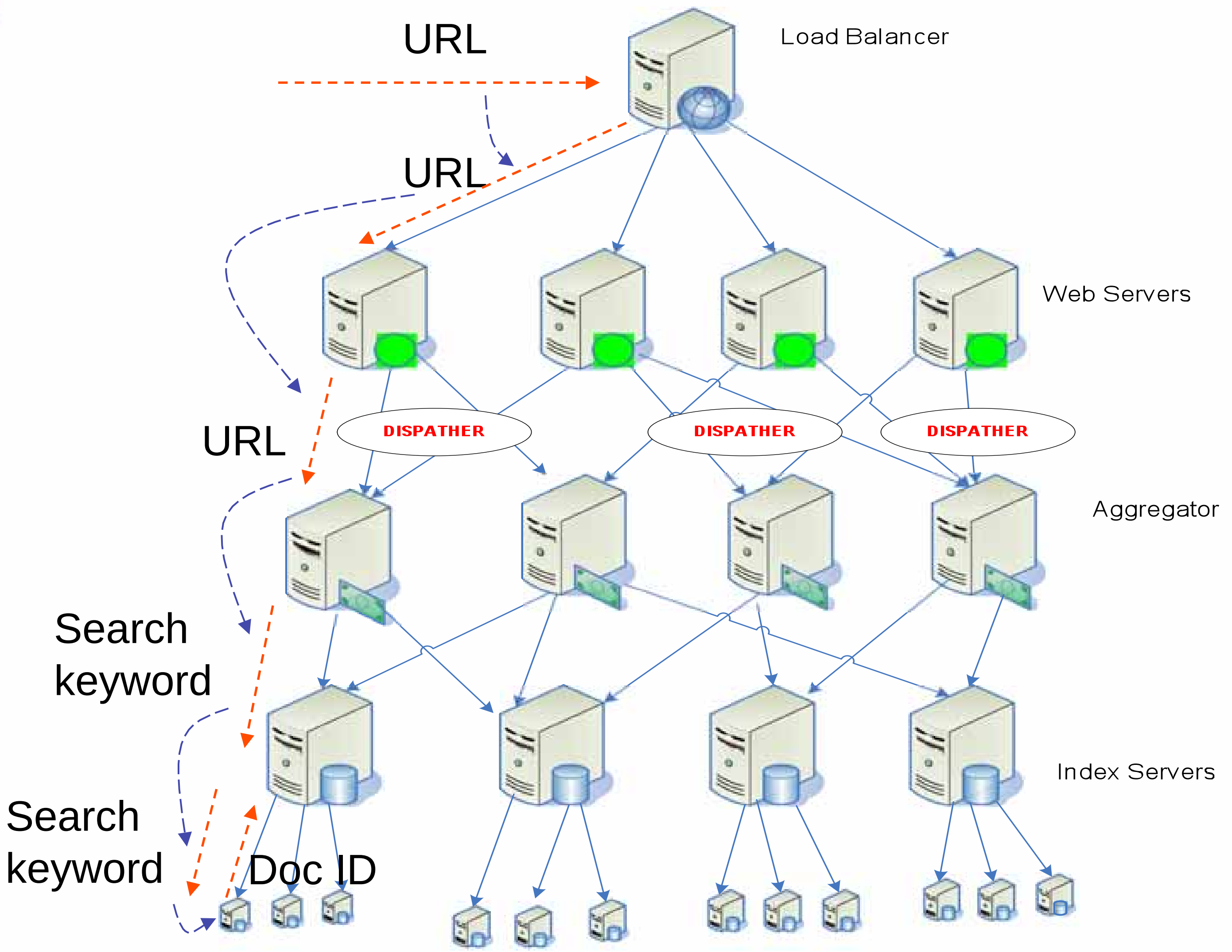
Related Work

Invasiveness / Application Knowledge	Non-Invasive			Invasive
	Network Sniffing	Interpo-sition	App or OS Logs	Source code modification
Black-box	Project 5, Sherlock	WAP5	Footprint	
Grey-box	Rake		Magpie	
White-box				X-Trace, Pinpoint

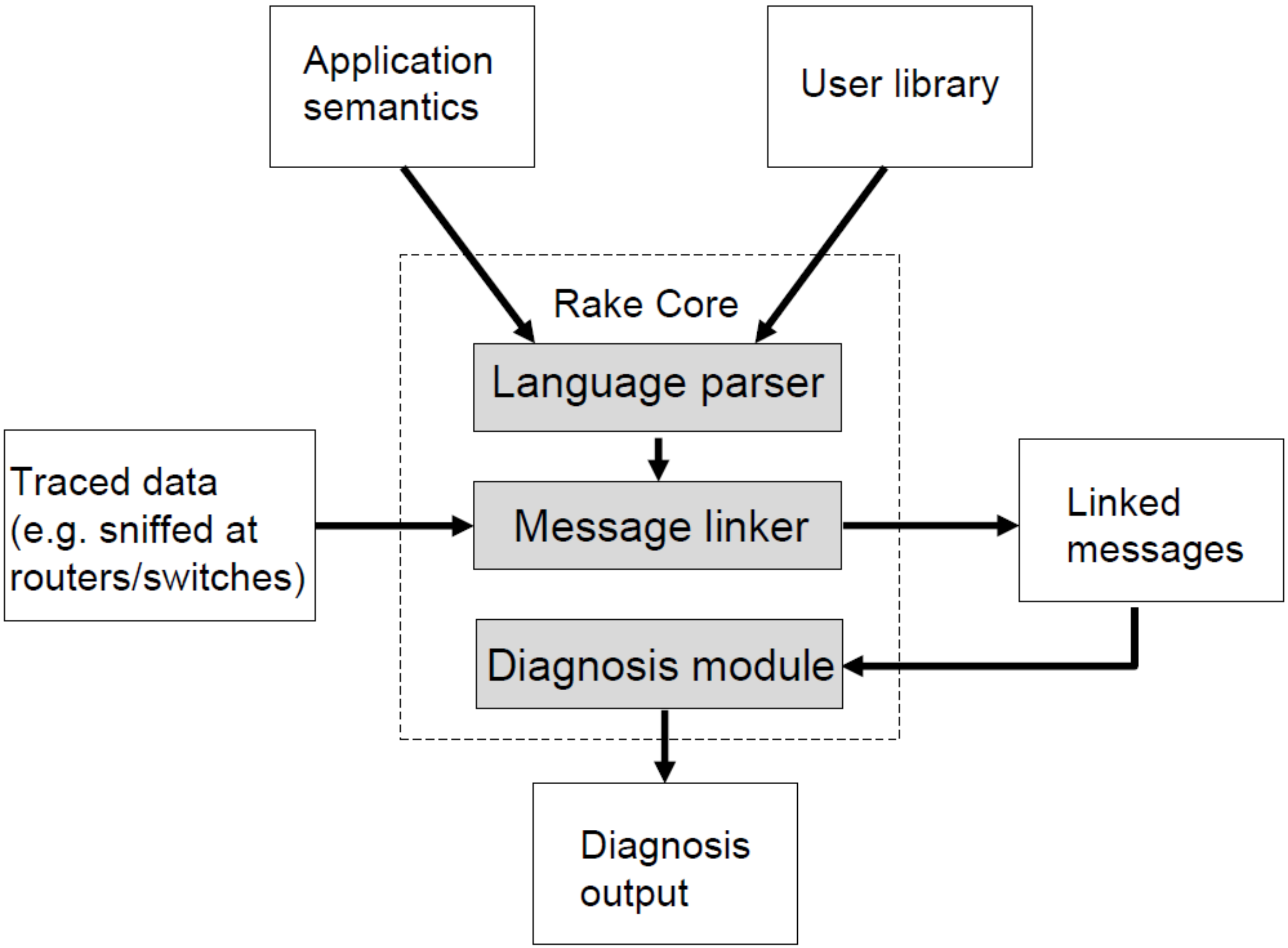
Rake

- Key Observations
  - Generally no unique ID linking the messages associated with the same request
  - Exist polymorphic IDs in different stages of the request
- Semantic Assisted
  - Use the semantics of the system to identify polymorphic IDs and link messages

Message Linking Example



Architecture of Rake



Questions on Semantics

- What Are the Necessary Semantics?
  - Use data flow analysis to automatically extract the invariants (and its transformation)
- How Does Rake Use the Semantics?
  - Naïve design is to implement Rake for each application with specific application semantics
- How Efficient Is the Rake with Semantics
  - Can message linking to accurate?
  - What’s the computational complexity of Rake?

Potential Applications

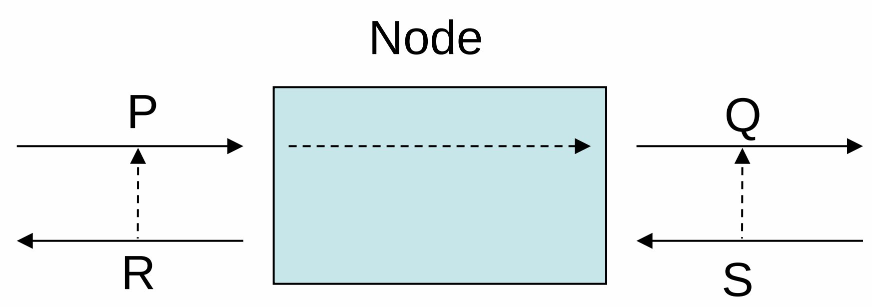
- Search
  - Verified by Microsoft collaborator
- CDN
  - CoralCDN is studied and evaluated
- Chat System
  - IRC is tested
- Distributed File System
  - Hadoop DFS is tested

Conclusions

- Feasibility/Applicability
  - Rake works for many popular applications in different categories
- Easiness
  - Rake allows user to write semantics via XML
  - Necessary semantics are easy to obtained given our experience
- Accuracy
  - Much more accurate than black-box approaches and probably matches white-box approaches
- Non-invasiveness

Necessary Semantics

- Intra-node linking
  - The system semantics
- Inter-node link
  - The protocol semantics

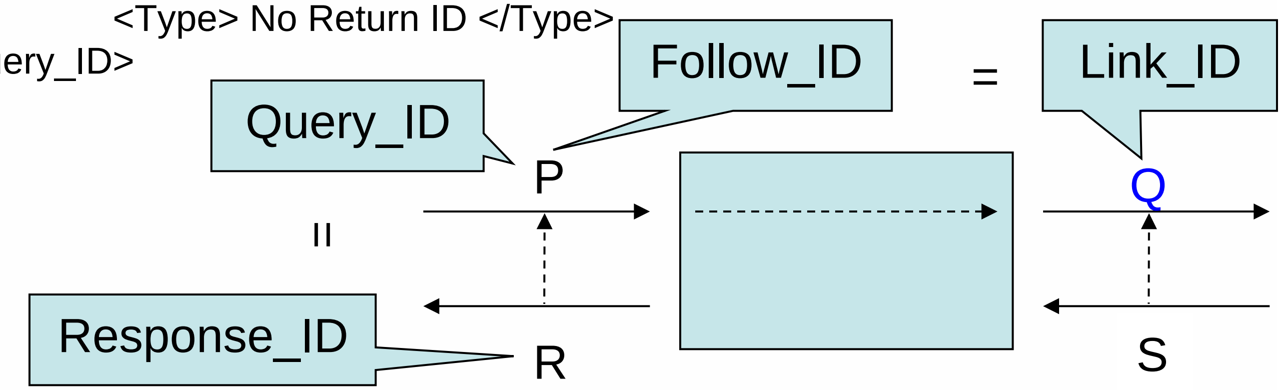


Utilize Semantics in Rake

- Implement Different Rakes for Different Application is time consuming
  – Lesson learnt for implementing two versions of Rake for CoralCDN and IRC
- Design Rake to take general semantics
  – A unified infrastructure
  – Provide simple language for user to supply semantics

Example of Rake Language (IRC)

- <?xml version="1.0" encoding="ISO-8859-1"?>
- <Rake>
- <Message name="IRC PRIVMSG">
- <Signature>
- <Protocol> TCP </Protocol>
- <Port> 6667 </Port>
- </Signature>
- <Link_ID>
- <Type> Regular expression </Type>
- <Pattern> PRIVMSG\s+(.*) </Pattern>
- </Link_ID>
- <Follow_ID id="0">
- <Type> Same as Link ID </Type>
- </Follow_ID>
- <Query_ID>
- <Type> No Return ID </Type>
- </Query_ID>
- </Message>
- </Rake>



Signature

- Signature to Classify Messages
  - <Signature>
    - <Protocol> TCP </Protocol>
    - <Port> 6667 </Port>
  - </Signature>
- Formats of Signatures
  - Socket information
    - Protocol, port
  - Expression for TCP/IP header
    - udp [10]&128==0
  - Regular expression
  - User defined function

Link_ID and Follow_ID

- Follow_IDs
  - The IDs will be in the triggered messages by this message
  - One message may have multiple Follow_IDs for triggering multiple messages
- Link_ID
  - The ID of the current message
  - Match with Follow_ID previously seen
- Linking of Link_ID and Follow_ID
  - Mainly for intra-node message linking

Query_ID and Response_ID

- Query_IDs
  - The communication is in Query/Response style, e.g. RPC call and DNS query/response.
  - The IDs will be in the response messages to this message
- Response_ID
  - The ID of the current message to match Query_ID previously seen
  - By default requires the query and response to use the same socket
- Linking of Query_ID and Response_ID
  - Mainly for inter-node message linking

Complicated Semantics

- The process of generating IDs may be complicated
  - XML or regular expression is not good at complex computations
  - So let user provide own functions
    - User provide share/dynamic libraries
    - Specify the functions for IDs in XML
    - Implementation using *Libtool* to load user defined function in runtime

Example for DNS

- <?xml version="1.0" encoding="ISO-8859-1"?>
- <Rake>
- <Message name="DNS Query">
- <Signature>
- <Protocol> UDP </Protocol>
- <Port> 53 </Port>
- <Expression> udp[10] & 128 == 0 </Expression>
- </Signature>
- <Link_ID >
- <Type> User Function </Type>
- <Libray> dns.so </Libray>
- <Function> Link_ID </Function>
- </Link_ID>
- <Follow_ID id="0">
- <Type> Link_ID </Type>
- </Follow_ID>
- <Query_ID>
- <Type> Link_ID </Type>
- </Query_ID>
- </Message>
- ………………………………

Extract the queried host

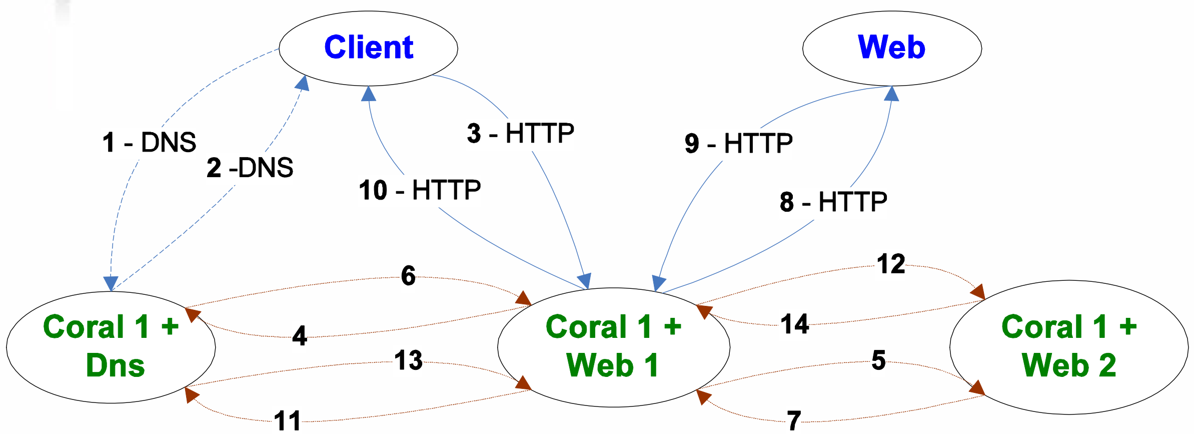
Accuracy Analysis

- One-to-one ID Transforming
  - Examples
    - In search, URL -> Keywords -> Canonical format
    - In CoralCDN, URL -> Sha1 hash value
  - Ideally no error if requests are distinct
- Request ambiguousness
  - Search keywords
    - Microsoft search data
    - Less than 1% messages with duplication in 1s
  - Web URL
    - Two real http traces
    - Less than 1% messages with duplication in 1s
  - Chat messages
    - No duplication with timestamps

Evaluation

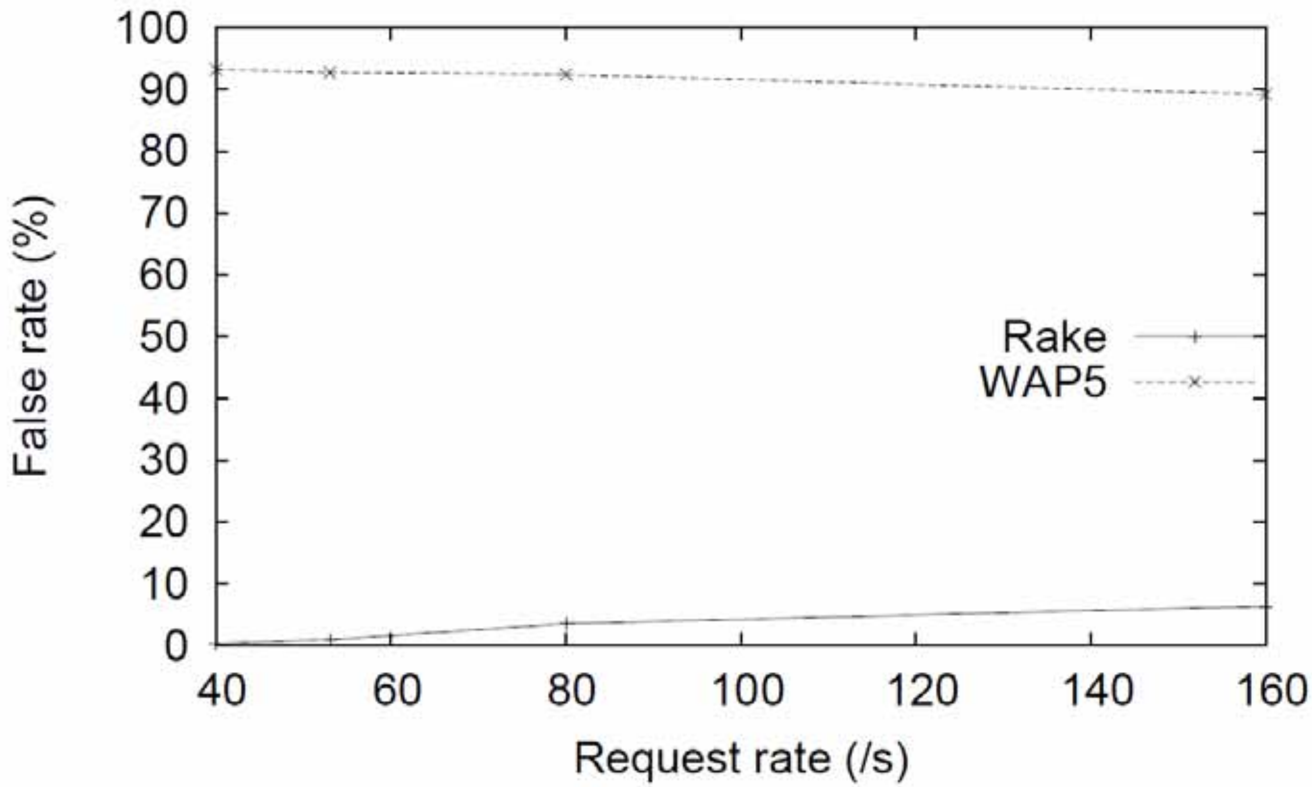
- Application
  - CoralCDN
  - Hadoop
- Experiment
  - Employ PlanetLab hosts as web clients
  - Retrieve URLs from real traces with different frequency
- Metrics
  - Linking accuracy (false positive, false negative)
  - Diagnosis ability
- Compared Approach
  - WAP5

CoralCDN Task Tree



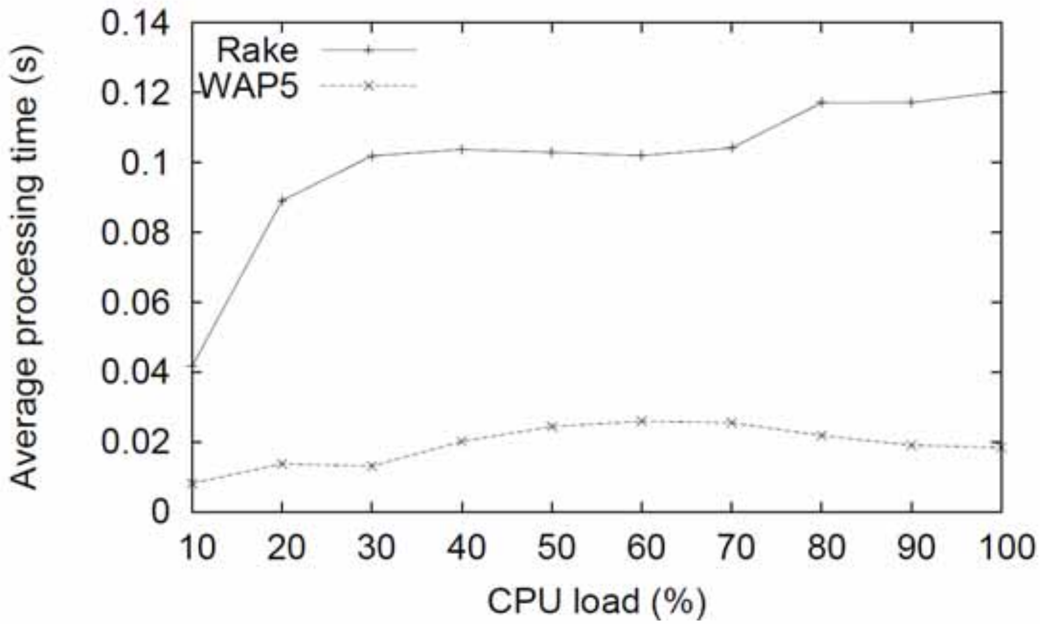
Message Linking Accuracy

- Use Log-Based Approach to Evaluate WAP5 and Rake Linking in CoralCDN



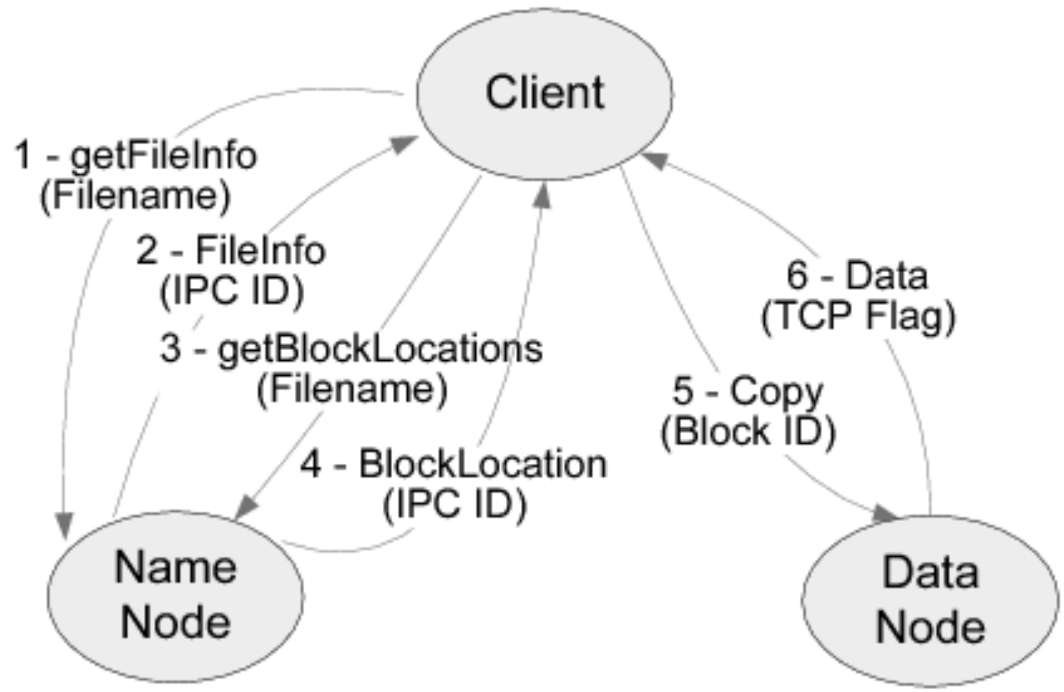
Diagnosis Ability

- Controlled Experiments
  - Inject junk CPU-intensive processes
  - Calculated the packet processing time using WAP5 and Rake

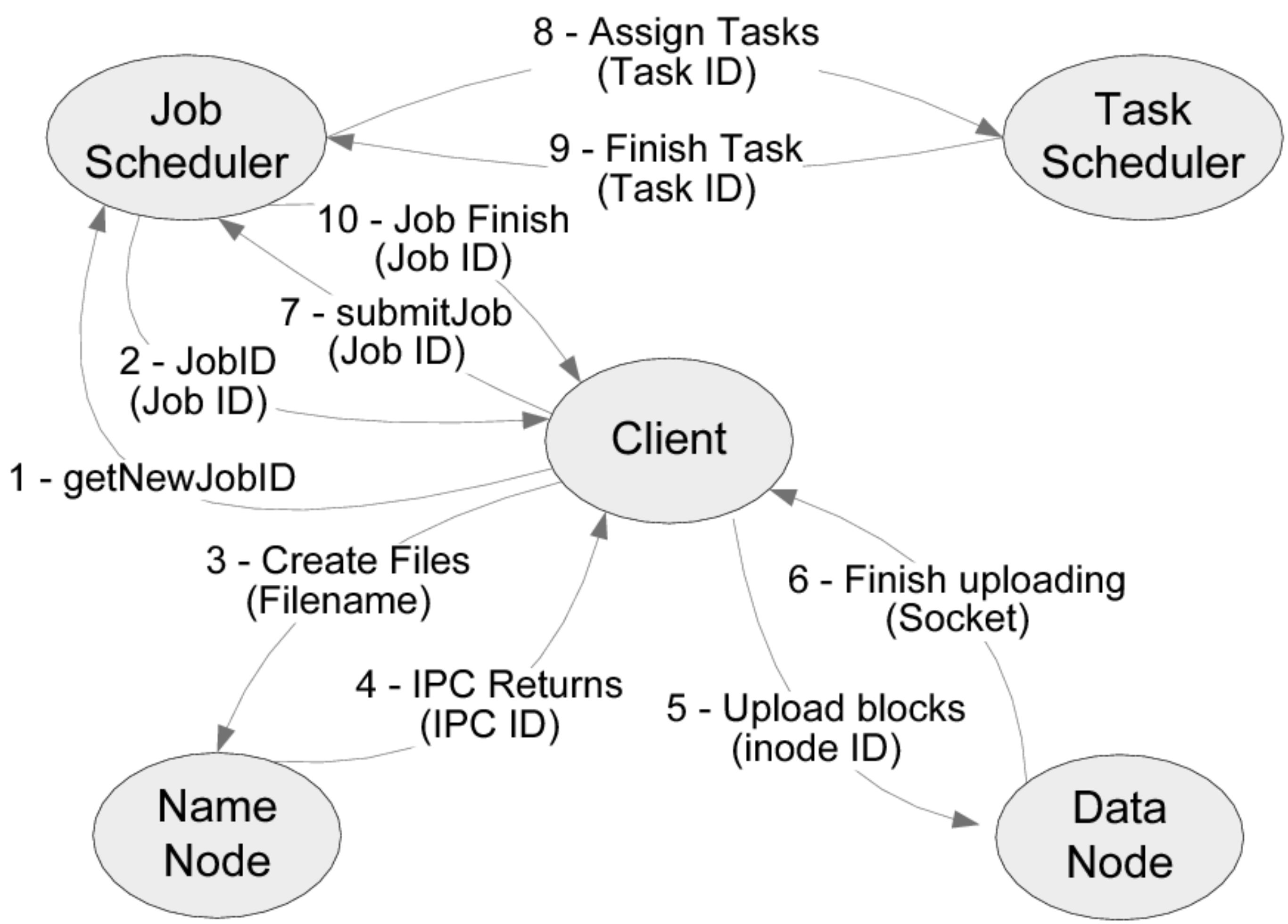


Obviously Rake can identify the slow machine, while WAP5 fails.

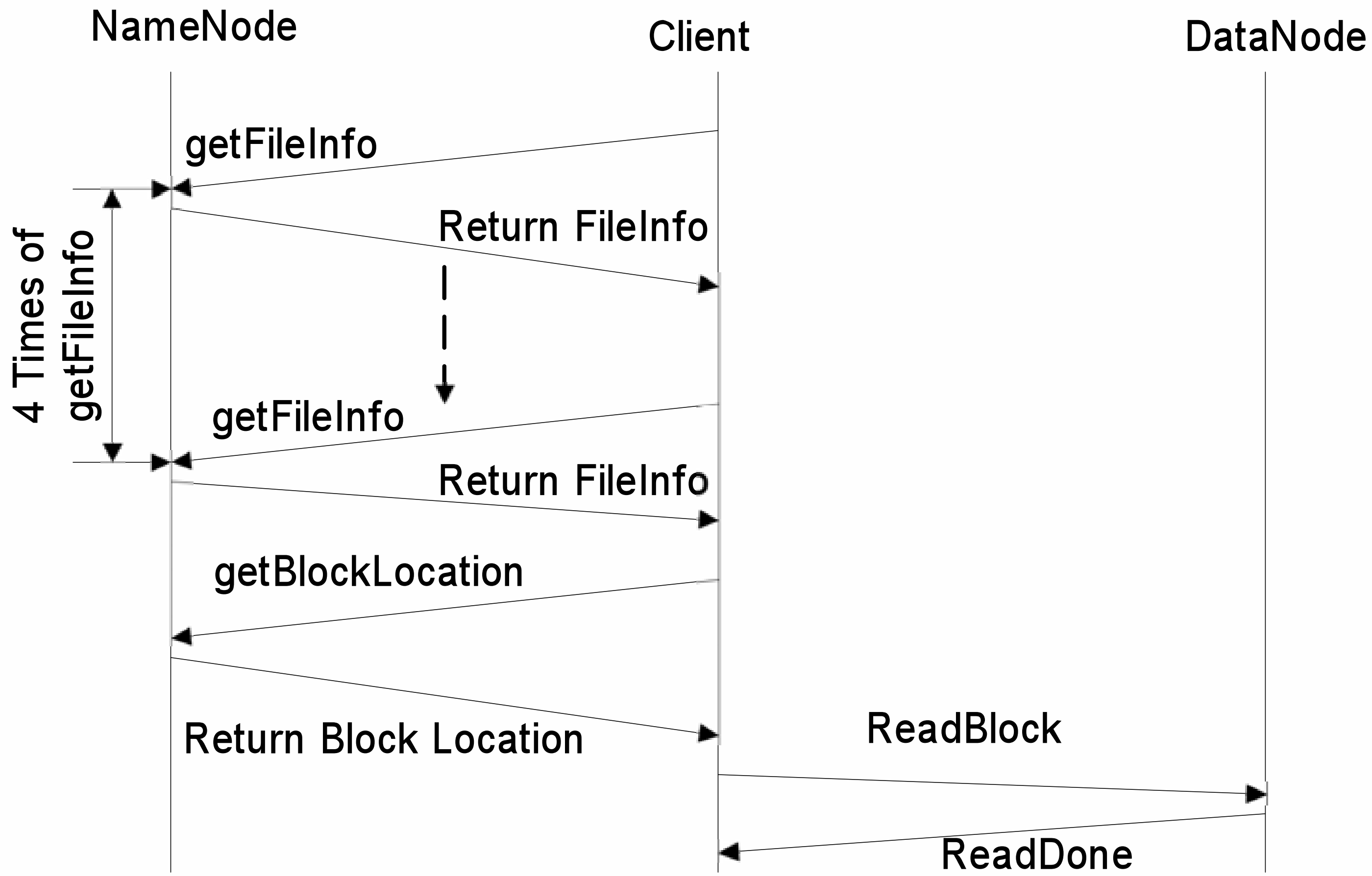
Semantics of Hadoop Get operation



Semantics of Hadoop Grep operation



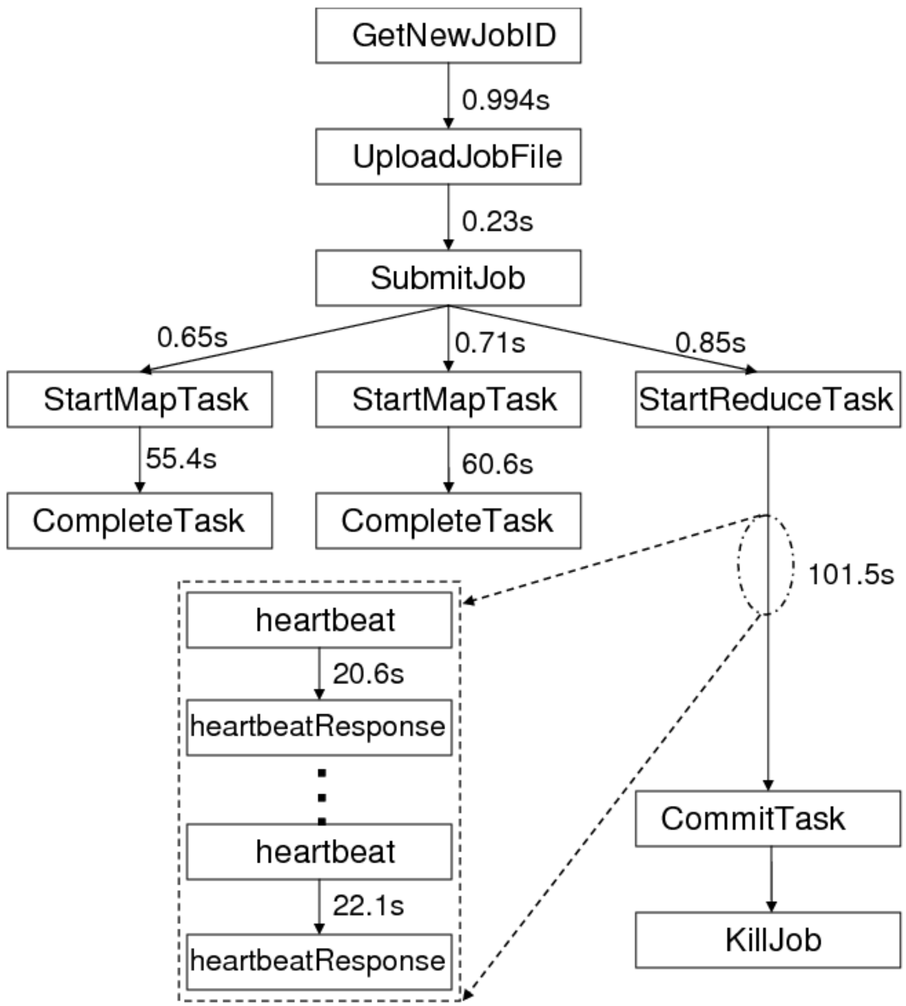
Abused IPC Call in Hadoop



It is a problem that we found in Hadoop source code.

Four “getFileInfo”s are used here, while only one is enough.

Running time of Hadoop steps



Discussion

- Implementation Experience
  - How hard for user to provide semantics
    - CoralCDN – 1 week source code study
    - DNS – a couple of hours
    - Hadoop DFS – 1 week source code study
- Inter-process Communication
- Encryption
  - Dynamic library interposition

Q & A?

Thanks!

Backup