Institute for Software Research
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DePaul University

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Architecturally Significant Requirements

- Play a strategic role in driving architectural design
- Often critical to the success (or failure of a system).
- Often represent quality concerns such as performance, portability, reliability etc.
- Non-functional Requirements (NFRs) are often overlooked in the requirements specification process.

Example: A medical device used to perform laser surgery must be highly responsive.
Talk Outline

- Architecturally Significant Requirements and their impact on architectural design.
  - Focus on agile projects
  - Examples from TraceLab project

- Establishing and utilizing trace links between quality concerns and code
  - Patterns of traceability
  - Archie tool

- Recovering architectural knowledge
  - Machine learning techniques
In practice ASRs (especially NFRs) are often not elicited and are not clearly specified.

Many Software Requirements Specifications simply don’t include NFRs.

Similarly, many agile projects fail to include ASR-related user stories.

**Is there a better way?**

In our TraceLab project we adopted a **persona-driven approach** which enabled us to **discover architecturally significant requirements** early in the project and to use our knowledge to make **informed decisions** about architectural design and implementation.
ASRs in TraceLab

- TraceLab is a US $2 Million Project funded by the National Science Foundation.
- Developed by collaborators at DePaul University, College of William and Mary, Kent State Univ., and Univ. of Kentucky.
- Intended to **empower future traceability research** through facilitating innovation and creativity, increasing collaboration between traceability researchers, decreasing the startup costs and effort of new traceability research projects, and fostering technology transfer.
- Provides an environment in which researchers can **design and execute experiments, share components and datasets, and comparatively evaluate results** in a controlled setting.
ASRs in TraceLab

Components Library
- Trace Classifier
  - Build Confusion Matrix
  - Classifier
  - Evaluation Loop Incrementation
  - Evaluation Loop Init
  - Evaluation Loop Start
- Exporters
- Helpers
- Importers
- Pick Classification Set
- Pick Training Set
- Remove underrepresented types
- Scatter To Buckets
- Top K Selector
- Training
- All Components
- Uncategorized
- Decision & Loops
- Goto Decision
- If Statement Decision (with scopes)
- While Loop

Recent Experiments
- Trace Classifier.tml
- Reporting demo.tml
- VectorSpaceStandardExperiment.tml
- BetaExperiment1.tml
- Non-normalized Cosine.tml
- JinsExperiment.tml
- StandardVSM.tml

Online Resources
- Wiki
  - Extensive documentation of TraceLab including experiment creation, component/datatype development and TraceLab framework architecture.
- Discussion Forum
  - Online site where users and developers can post messages and discuss topics related to TraceLab.
- Issue Tracker / Bug Reporting
  - Site that manages and maintains a list of issues regarding TraceLab framework and components.
- COEST
  - Overview of the Center of Excellence for Software Traceability and its ongoing projects (including TraceLab).
We want to write components in C#.

We’re programming this thing and we say that we should just program for Windows and everyone will have to use Windows.

It’s going to work on Mac, right?

We need to cut across the chaos.

I don’t want to do any programming.

I want to just reuse my R and MatLab scripts.

I don’t want to do any programming.

I want to just reuse my R and MatLab scripts.

It better be as fast as running experiments that I write to myself.

I only know java. I’m not learning another language.

We should get this into the hands of our users early so we can get early feedback.

I just want it to install and run easily.

We only have 3 years to deliver everything!!

I’m willing to share with others, but not until after I’ve published.

Can you offer it as a service?

I have to run it on my desktop as I have proprietary data.

Our lab does everything on Linux.

No way.

I need to be able to write my own components.

No way.

I need to be able to write my own components.
We decided to represent the conflicting needs through developing a set of architecturally-savvy personas. Traditionally persona construction involves surveying users, classifying them, formulating hypotheses of use, validating, creating scenarios, and finally designing personas.

Too time consuming for our project i.e. too much upfront effort that would retard the achievement of our goals.

Solution: **Persona sketches.**
Architecturally-Savvy Personas (Lite)

Tom: Age: 59, Professor
- Fast trace retrieval
- Platform selection
- Language selection
- Reliability
- Extensibility
- Ease of component upload
- Ease of installation
- Highly intuitive interface
- Extensive document compatibility
- Data confidentiality
- Broad adoption

Tom is a long time traceability researcher. He has published numerous papers that have focused on tracing from source code to design and requirements. He has focused on using LDA, LSI, and various probabilistic approaches. He has also developed algorithms for visualizing the results of his traces.

Tom prefers coding in C++ on Linux. He plans to contribute components to the TRACY project; however, he already has an established traceability research environment and therefore may not use all the TRACY features himself.

**My user stories:**
1. I need to be able to write components in C++ and integrate them easily into TraceLab experiments.
2. Experiments that I run using TraceLab must not take about the same amount of time to run as my existing experiments.
3. I need to be able to run TraceLab on Linux.
4. I need accessibility to benchmarks so I can compare new algorithms and techniques against previous results.
5. I need access to datasets with existing trace matrices.

**My anti-stories:**
1. I won’t use TraceLab if it is buggy and keeps breaking.

Jane Cleland-Huang, Adam Czauderna, Ed Keenan: A Persona-Based Approach for Exploring Architecturally Significant Requirements in Agile Projects. [REFSQ 2013](#): 18-33
Meet Karly...

Karly is a new PhD student. She is interested in tracing requirements to software architecture.

She has contacts with a local company who will allow her to access their data for her experiments; however this data is proprietary (i.e. protected by a NDA) and so she cannot share it with anyone else.

She predicts that it will take her about 6 months to set up her traceability environment, but then she discovers TRACY. Karly is quite a good programmer, but is much more interested in the process side of her research.

**My user stories:**

1. I need to be able to maintain confidentiality of my data.
2. I need to be able to create my own components and integrate them with existing experiments.
3. I need to be able to setup new benchmarks for comparative purposes.
4. I need to be able to program components in C#.
Meet Jack...

Jack is married and has two young children. He has recently been hired by the TRACY project into the role of Software Architect/Developer. He has 6 years of experience as a software developer and 2 years as a lead architect in a successful gaming company. He has taken the job on the TRACY project because he is excited by the challenge of working in a research oriented project.

Jack is very motivated to build a high quality product. Jack has never worked in an academic research setting before. He is very collaborative and is looking forward to working with the other developers, academics, and students on the project.

My user stories:

1. I need to develop the TraceLab framework in a language which supports rapid prototyping.
2. I need the framework language to easily interface with, and call, components written in other languages.
3. I need the platform to provide natural support for the separation of model and view components.
4. I need libraries to support GUI development.
Meet the full ensemble...

Tom

Glen
Age: 23
MS Student at Hillsbury College

Glen is an MS student who has been helping his advisor to build TraceLab components. He has never contributed to an open source project before, so he needs to figure out how to make contributions to TraceLab. Glen is very collaborative and is looking forward to working with the other researchers on the project.

Wayne
Age: 46
Technical Project Mgr
ABC Corp

Wayne is the technical manager for a very large systems engineering project. He could be described as an early adopter, as he prides himself in keeping an eye out for good ideas that could help his organization. Wayne wants to improve the efficiency of traceability practices in his organization and is interested in using TraceLab.

Mary
Age: 51
NSF Program Officer

Mary is the funding officer for the grant. She is concerned that the project delivers on time and ultimately meets all major goals in terms of adoption, research advancements, and technology transfer.
## Understand key concerns

<table>
<thead>
<tr>
<th>Decision: Pertinent user stories:</th>
<th>Platform/Language</th>
<th>Tom</th>
<th>Janet</th>
<th>Karly</th>
<th>Jack</th>
<th>Mary</th>
<th>Wayne</th>
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<td>US 2. Users must be able to write and integrate components from multiple languages</td>
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<td>US 3. The source language of each component must be invisible at runtime</td>
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<td>US 4. The selected language/platform must support rapid framework prototyping</td>
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<td>US 5. The selected GUI must deliver ‘razzle dazzle’</td>
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<td>✔️</td>
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<th>Architectural Decisions</th>
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<tbody>
<tr>
<td>AD 1. Build framework using Visual Studio.net and C#</td>
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<td>AD 2. Develop the initial Windows-specific GUI in WPF</td>
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| AD 3. Utilize MVVM (model view view model) architectural pattern, so that (a) the GUI View is loosely coupled and can be later implemented using GTK or Windows Forms and compiled for multiple platforms, and (b) the TraceLab engine can be compiled using Mono for porting to Linux and Mac environments | | | | | | | |}

### Process steps:
1. Analyze persona needs.
2. Identify primary drivers.
3. Extract all related user stories.
4. Assign to personas.
5. Brainstorm architectural design solutions and evaluate leading contenders.
6. Evaluate against personas.
Process steps:

7. Identify architectural risks associated with the proposed solution and their mitigations.
8. Consider and document impacts upon personas.
Architectural design

WPF UI Layer

- TraceLab.UI.WPF: Workspace View Model Wrapper
- TraceLab.UI.WPF: Components Library Window
- TraceLab.UI.WPF: Experiment View
- TraceLab.UI.WPF: Other Interactive views

Views UI (xaml) - TraceLab.UI.WPF

- Wrappers around View Models. WPF and UI specific code is added here.

TraceLab.UI.WPF

- Application/ViewModelWrapper
- Component Library View Model Wrapper
- Components Library Window
- Experiment View
- Experiment View Model
- Other interactive views
- Workspace View Model Wrapper
- Workspace Window

TraceLab.UI.WPF is the only package that is WPF specific. Several View Models have their WPF specific wrappers around the actual View Model in the TraceLab.Core.

TraceLab.Core.dll

- Core View Models (TraceLab.Core.dll)

- Workspace View Model
- TraceLab.Core: Components Library View Model

- Workspace: Workspace (Shared data repository)
- TraceLab.Core: Component Library
- TraceLab.Core: Experiment

Models - (TraceLab.Core.dll)

- Start Node
- Component Node
- Decision Node

(from TraceLab.Core)
(from TraceLab.Core)
(from TraceLab.Core)

Supports build-now/port-later decision
## Decision 2: Workflow architecture

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<tr>
<th>Decision:</th>
<th>Workflow Architecture</th>
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<td><strong>Pertinent user stories:</strong></td>
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<td>US 1.</td>
<td>The TraceLab environment must support plug and play.</td>
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<td>US 2.</td>
<td>The performance penalty of using TraceLab must be low (i.e. close to runtime of non-TraceLab experiments).</td>
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<td>US 3.</td>
<td>Components should be reusable across research groups and experiments.</td>
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<td><strong>Architectural Decisions:</strong></td>
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<td>AD 1.</td>
<td>Utilize a blackboard architecture.</td>
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<td>AD 2.</td>
<td>Create standard data types for exchanging data between components.</td>
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<td>AD 3.</td>
<td>Construct the experiment around the concept of a workflow.</td>
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<td>AD 4.</td>
<td>Support concurrent execution of components.</td>
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<td>AD 5.</td>
<td>Trust the TraceLab users to create a viable workflow. Provide basic type checking only.</td>
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<tr>
<td><strong>Risks:</strong></td>
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<tr>
<td>R 1.</td>
<td>Performance may suffer as data is exchanged between components via shared memory.</td>
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<td>R 2.</td>
<td>If TraceLab users proliferate the creation of data types, then plug-and-play ability will be lost.</td>
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<td><strong>Personal Impacts:</strong></td>
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<tr>
<td>PI 1.</td>
<td>All personas are satisfied with the plug-and-play solution.</td>
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<tr>
<td>PI 2.</td>
<td>The performance penalty will be felt more by Tom, as he already has a functioning tracing environment. For other researchers the benefits of the plug-and-play environment and the use of previously defined tracing components far outweighs the slight performance penalty.</td>
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### Options
- Pipe-and-filter
- Services
- Precedence graph + Blackboard
Decision 2: Workflow architecture
Our approach is generalizable.

We created five Architecturally Savvy Personas for a Mechatronics Traceability project that we are working on with Siemens.

The personas highlighted different kinds of concerns from those highlighted by the TraceLab personas.

**Elaine** is a mechanical engineer with over 20 years of experience working for Company X. She is in charge of modeling the mechanisms for a railway gate. Her model needs to integrate with other models that describe the signaling process for the railway system. Elaine is aware that the crossing-gate must comply to a number of regulatory codes and she would like to be able to view the relevant codes from within her model. Elaine has access rights to update her model and to read requirements.

**Elaine's user stories:**
1. I need to be able to access all regulatory codes that impact the model I am currently working on.
2. I would like to control who views the models I am working on, and which version they view.
3. When I trace between my model and requirements, I need the traces to be returned within 30 seconds.
4. I need trace information to be displayed as an integral part of the model I am working in.

**John** is the compliance officer for company X. His job is to ensure that all regulatory codes are met by the delivered product and to generate reports to demonstrate this. He is a very detail-oriented person and takes great pride in his job. No products have ever been recalled under his watch for non-compliance purposes.

**John's user stories:**
1. I need to be able to generate a report which shows a list of all elements in the design that help satisfy each relevant regulatory code. The report should generate within 2 minutes.
2. I need to view traces created in a wide variety of products.
3. I need to be able to generate and view traces for remote (i.e. globally distributed) models.
SCRUM+ ASPs

1. Identify preliminary personas
2. Elaborate individual personas and explore quality concerns
3. Explore architectural decisions and trade-offs
4. Break architecture into sprint-sized chunks
5. Select features plus their associated architectural components for the Sprint backlog
6. Evaluate solution with respect to persona’s goals
7. Update personas

- Identify preliminary personas
- Elaborate individual personas and explore quality concerns
- Explore architectural decisions and trade-offs
- Break architecture into sprint-sized chunks
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- Update personas

Daily scrum meeting
24 hours
30 days
Backlog tasks expanded by team
Construct software, including architecture, incrementally.
Deliver potentially shippable product.

Product backlog of features as prioritized by customer
Sprint-sized architectural chunks associated with specific features.
So what did we learn?

- Emerging and analyzing quality concerns early allowed us to make more informed architectural decisions.
- Sketching out architecturally savvy personas (ASPs) enables us to think about quality concerns in a more tangible way.
- Our approach fits naturally into the SCRUM-like process we had adopted for the project.
- A light-weight approach for integrating NFR-thinking into a fast-paced, agile, development environment.
Talk Outline

- Architecturally Significant Requirements and their impact on architectural design.
  - Focus on agile projects
  - Examples from TraceLab project

- Establishing and utilizing traceability links between quality concerns and code
  - Patterns of traceability
  - Archie tool

- Recovering architectural knowledge
  - Machine learning techniques
Ideal World: Architectural information is documented during the Architectural design phase and is updated regularly to reflect the current system architecture.

*Slide used courtesy of Mehdi Mirakhorli*
Real World: Architectural information is outdated and does not reflect the current architecture of the system.

*Slide used courtesy of Mehdi Mirakhorli*
Architectural Degradation

1. Intended and implemented architecture diverge.

2. Architecture violations (i.e. strict layering bypassed, or pipe-and-filter pipeline violated); cyclic dependencies; dead code; code clones; metric outliers etc.

System becomes brittle starts to erode.
Requirements traceability is the ability to describe and **follow the life of a requirement**, in both a forward and backward direction, i.e. from its origins, through its development and specification, to its subsequent deployment and use, and through periods of ongoing refinement and iteration in any of these phases.”

We can use the Softgoal Interdependency Graph (SIG) notation to capture the goal refinements that lead to our architectural decisions.

Only certain kinds of architectural decisions are traceable to code.
A custom view shows the impact of the architectural decision to pass data using serialization, on higher level quality concerns.
Customized Views

A persona / user perspective upon architectural decisions.
Some decisions occur across multiple projects

Can we find better ways to trace quality concerns to code when common architectural decisions are made?
Some decisions recur across projects

Due to complexity of the problem, we tackled tactics first.

- Tactics are pervasive in fault-tolerant and/or high-performance systems.
- Tactics seem to have an interesting relationship to change.
### Tactic Occurrence Across Projects

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<td>6 SmartFog: Distributed Application Development Framework</td>
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<td>7 CarDamon: Real-time, distributed and fault-tolerant middleware</td>
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<td>16 Airbus Family: Flight Control System*.</td>
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<td>17 Boeing 777: Primary Flight Control (PFC)*.</td>
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<td>18 NASA CEV: Crew Exploration Vehicle using guidance-navigation* &amp; control model.</td>
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<td>19 Hadoop Framework: a development framework to support cloud computing.</td>
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<td>20 OfBiz: an enterprise automation and E-Commerce software.</td>
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</tbody>
</table>

Courtesy Mehdi Mirakhorli

Tactics tend to be found in safety-critical, and/or other kinds of performance-centric systems.
Tactic Traceability Patterns

- Mehdi Mirakhorli and Jane Cleland-Huang, “A Pattern System for Tracing Architectural Concerns”, Pattern Languages of Programming, Portland, USA, October, 2011
Archie...
Talk Outline

- Architecturally Significant Requirements and their impact on architectural design.
  - Focus on agile projects
  - Examples from TraceLab project

- Establishing and utilizing traceability links between quality concerns and code
  - Patterns of traceability
  - Archie tool

- Recovering architectural knowledge
  - Machine learning techniques
In contrast, architectural concerns are often NOT unique in individual systems – so we can train our traceability engine to recognize them across projects.
Tactic Detector

Our tactic detector uses a previously designed classifier – now implemented in TraceLab.
Classification Approach

1. Normalizes the frequency with which term t occurs in the requirement with respect to the length of the requirement.

2. Computes the percentage of documents of type Q containing term t

3. Decreases the weight of terms that are project specific.

\[
Pr_Q(t) = \frac{1}{N_Q} \sum_{r_Q \in S_Q} \frac{freq(r_Q, t)}{|r_Q|} \cdot \frac{N_Q(t)}{N(t)} \cdot \frac{NP_Q(t)}{NP_Q}
\]

\[
Pr_Q(r) = \frac{\sum_{t \in r \cap I_Q} Pr_Q(r)}{\sum_{t \in I_Q} Pr_Q(t)}
\]

### Towards Automation

<table>
<thead>
<tr>
<th>Tactic Name</th>
<th>Document trained indicator terms</th>
<th>Code trained indicator terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartbeat</td>
<td>heartbeat, fault, detect, message, period, watchdog, send, tactic, failur, aliv</td>
<td>heartbeat, ping, beat, heart, hb, outbound, puls, hsr, period, isonlin</td>
</tr>
<tr>
<td>Scheduling</td>
<td>prioriti, schedul, assign, process, time, queue, robin higher, weight, dispatch</td>
<td>schedul, task, priorit, prcb, sched, thread, , rtp, weight, tsi</td>
</tr>
<tr>
<td>Authentication</td>
<td>authent, password, kerbero, sasl, ident, biometr, verifi, prove, ticket, purport</td>
<td>authent, credenti, challeng, kerbero, auth, login, otp, cred, share, sasl</td>
</tr>
<tr>
<td>Resource Pooling</td>
<td>thread, pool, number, worker, task, queue, executor, creat, overhead, min</td>
<td>pool, thread, connect, sparrow, nbp, processor, worker, timewait, jdbc, ti</td>
</tr>
<tr>
<td>Audit Trail</td>
<td>audit, trail, record, activ, log, databas, access, action, moni-tor, user</td>
<td>audit, trail, wizard, pwriter, lthread, log, string, categori, pstmt, pmr</td>
</tr>
</tbody>
</table>
Tactic-Grained Classification

Legend

- 0.001 term threshold
- 0.005 term threshold
- 0.01 term threshold
- 0.05 term threshold
- 0.1 term threshold
Tactic-trained Classification / Code Trained

Legend

- - - - 0.001 term threshold  
- - - 0.005 term threshold  
- - - - - 0.01 term threshold  
- - - - - - 0.05 term threshold  
- - - - - - - - - 0.1 term threshold
# HADOOP Case Study

<table>
<thead>
<tr>
<th>Tactic</th>
<th>Class Count</th>
<th>Explanation</th>
<th>Package name or Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heartbeat</td>
<td>12</td>
<td>HDFS uses a master/slave architecture with replication. All slaves send a heartbeat message to the master server indicating their health.</td>
<td>MapReduce Subsystem</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>The MapReduce subsystem uses heartbeat with piggybacking to check the health and execution status of each task running on a cluster.</td>
<td>HDFS Subsystem</td>
</tr>
<tr>
<td>Resource Pooling</td>
<td>36</td>
<td>MapReduce uses Thread pooling to improve performance of many tasks e.g. to run the map function.</td>
<td>Mapreduce Package</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>A global compressor/decompressor pool used to save and reuse codecs.</td>
<td>Compress package</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>Block pooling is used to improve performance of the distributed file system.</td>
<td>HDFS subsystem</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Combines scheduling and job pooling. Organizes jobs into pools, and shares resources between pools.</td>
<td>MapReduce Subsystem</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>Scheduling services are used to execute tasks and jobs. These include fair-, dynamic-, and capacity-scheduling.</td>
<td>Common and MapReduce Subsystem</td>
</tr>
<tr>
<td>Scheduling</td>
<td>4</td>
<td>Audit log captures user activities and authentication events.</td>
<td>Mapreduce package</td>
</tr>
<tr>
<td>Audit Trail</td>
<td>35</td>
<td>Users Kerberos and other subsystems.</td>
<td></td>
</tr>
<tr>
<td>Authentication</td>
<td></td>
<td>The MapReduce authentication system captures user activities.</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing metrics for different components of Hadoop]
More Challenging: Identifying Roles

- **Reliability goal**
- **Availability goal**

Heartbeat tactic helps Reliability goal and Availability goal.

**Rationale** justifies Heartbeat tactic.

Heartbeat tactic is realized by Requirement.

- **Emitter** emits heartbeat.
- **Receiver** receives heartbeat.
- **Fault Monitor** is monitored by Heartbeat tactic.

<<Component> Emitter

- Emits pulse

<<Component> Receiver

- is monitored by Fault Monitor

<<Component> Fault Monitor

- maps
Finding Roles is Hard

We integrated light-weight structural approaches – but only evaluated them in a single case study.
Tactic-trained Classification / Code Trained

HDFS must store data reliably even in the presence of failures.

Note: We did not train the classifier to detect fault monitors and so they are excluded from this model.

- 0.61 Receiver
- 0.54 Emitter

- 0.62 Receiver
- 0.60 Emitter

- 0.62 Receiver
- 0.61 Receiver
- 0.51 Emitter
- 0.59 Emitter

- 0.59 Emitter
- 0.46 Receiver

UpgradeDatanode.java
- 0.79 Emitter
- 0.75 Receiver

BlockManager.java
- 0.58 Receiver
- 0.46 Emitter
Using Generated Links to mitigate Architectural Decay

- Are automatically reconstructed traceability links good enough for use?
- Evaluated the usefulness of the generated fine-grained traceability links for supporting software maintenance.
- Utilized Hadoop change logs for the past four releases, and simulated the scenario in which generated links were used to control the generation of notification messages.

You are modifying `Datanode.java`. This file appears to play the role of heartbeat emitter in the heartbeat tactic.

This class therefore contributes to reliability and availability goals. Tell me more.

Please confirm the role of this class in the heartbeat tactic:

- [✓] Heartbeat emitter (Prob 79%)
- [ ] Heartbeat sender (Prob 75%)
- [ ] Supporting role
- [ ] Unrelated to heartbeat
Visualizations
Conclusions

- Managing quality concerns (aka NFRs) is a complete life-cycle activity.
- Elicit them early
- Design to satisfy them
- Preserve them
- If necessary, rediscover them
Developing automated tools to minimize the cost and effort of traceability.

Tackle cutting edge problems in software traceability.

Center of Excellence for Software Traceability

The vision of the Center of Excellence for Traceability (CoEST) is to provide leadership for traceability research, education, and practice; promoting the pursuit of excellence from research idea to practice, based on a foundation of innovative, ethical, collaborative work.

Build a supportive community of researchers.
Any questions?

Preserving, Generating, and Visualizing Knowledge of Architecturally Significant Requirements in Source Code

Institute for Software Research
Distinguished Speaker Series
University of California, Irvine
April 19th, 2013
Dr. Jane Cleland-Huang
DePaul University

Research funded by the US National Science Foundation under Major Research Instrumentation Grants CCF-0959924 and CCF-1265178.