Using ODC for Empirical Evaluation of Software Anomalies

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Topics

- Overview of ODC
- Sample Results
  - Mars Exploration Rover
  - Deep Impact & Stardust
  - Technology Infusion
  - Dissemination
- Benefits for Moon/Mars Human Space Flight Missions
Overview

• **Goal:**
  1. To characterize software anomalies, using data from multiple spacecraft projects, by means of a defect-analysis technology called *Orthogonal Defect Classification (ODC)*.
  2. To support transfer of ODC to NASA projects through applications and demonstrations.

• **Approach:**
  1. Analyze anomaly data using adaptation of *Orthogonal Defect Classification (ODC)* method
     • Developed at IBM; widely used by industry
     • Quantitative approach
     • Used here to detect patterns in anomaly data
  2. Adapt ODC for NASA use and apply to NASA projects
Overview: Status

- Previous work used ODC to analyze safety-critical \textit{post-launch} software anomalies on 7 spacecraft.
- FY'03 task extended ODC work to \textit{pre-launch development and testing} (Mars Exploration Rover testing, Deep Impact, contractor-developed software) and supported \textit{technology infusion}
- Adapted ODC categories to spacecraft software at JPL:
  - Activity: what was taking place when anomaly occurred?
  - Trigger: what was the catalyst?
  - Target: what was fixed?
  - Type: what kind of fix was done?
Example: Lesson Learned from ODC

MER software defects; distribution of Types* x Target** (6/03)

*What kind of fix?
**What was fixed?

Why so many With "No fix"?

What's going on here? Investigate this pattern further!

*What kind of fix?
**What was fixed?
Example: Lesson Learned from ODC

"Crystal Ball": If software behavior surprised testers, it may surprise operators

- Testing problem reports give "crystal ball" into operations
  - False-positive testing problem reports (where software behavior is correct but unexpected) provide insights into requirements confusions on the part of users

- Closing problem reports with "No-Fix-Needed" decision can waste opportunity to document/train/change procedure
  - Avoid potentially hazardous recurrence
  - Important in long-lived systems with turnover, loss of knowledge
# ODC Values for Test Anomalies

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Activity</th>
<th>Build Test</th>
<th>Avionics I&amp;T</th>
<th>ATLO</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capability Invocation</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Command Execution</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HW Configuration</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HW-SW Interaction</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inspection/Review</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SW Configuration</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Special Procedures</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Start/Restart, Shutdown, Reboot</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Workload &amp; Stress</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
## ODC Values for Test Anomalies

<table>
<thead>
<tr>
<th>Target</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assignment/Initialization</td>
<td></td>
</tr>
<tr>
<td>Flight Rule</td>
<td></td>
</tr>
<tr>
<td>Ground Software</td>
<td>Function/Algorithm</td>
</tr>
<tr>
<td></td>
<td>Interfaces</td>
</tr>
<tr>
<td></td>
<td>Testbed environment</td>
</tr>
<tr>
<td></td>
<td>Timing</td>
</tr>
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<td>Timing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Build/Package</th>
<th>Install Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Info. Development</td>
<td>Scripts</td>
</tr>
<tr>
<td></td>
<td>Version conflict</td>
</tr>
<tr>
<td></td>
<td>Documentation</td>
</tr>
<tr>
<td></td>
<td>Missing procedures</td>
</tr>
<tr>
<td></td>
<td>Procedures not followed</td>
</tr>
<tr>
<td>Hardware</td>
<td>Hardware</td>
</tr>
<tr>
<td>None/Unknown</td>
<td>Nothing Fixed</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Use on MER of ODC* defect analysis

*ODC = Orthogonal Defect Classification technique [IBM]

Recommendations for MER and future projects:
- Earlier assignment of criticality ratings
- If software's behavior confused testers, enhance documentation
- Earlier testing of fault-protection

MER use:
- Improved understanding of data, underlying causes, defect mechanisms
- Develop and package recommendations for MER
- Implement/defer recommendations

MER use:
- Identify patterns of concern for more investigation
- MER use: Browse pivot chart (Excel) for overview/closer look at testing
- MER use:
- Discover defect patterns in testing of interest to MER
- Perform Root Cause Analysis on subset
- Where are the spikes?
- Phase-by-phase deltas?
- Activity/Trigger/Target/Type look nominal?
- How many problem reports result in requirements discovery?
- Improvement release-by-release uneven: why?
- Many closed with no fix: why?
Results: **MER**

- Collaborated with Mars Exploration Rover to experimentally extend ODC approach to pre-launch software problem/failure testing reports (~800)
  - Adjusted ODC classifications to testing phases
  - Institutional defect database → Access database of data of interest → Excel spreadsheet with ODC categories → Pivot tables with multiple views of data
  - Frequency counts of Activity, Trigger, Target, Type, Trigger within Activity, Type within Target, etc.
  - User-selectable representation of results support tracking trends and progress:
    - Graphical summaries
    - Comparisons of testing phases
  - Provides rapid quantification of data
  - Project provides feedback/inquiries on our monthly deliverables of results and on our draft reports/paper
Results: MER software defects

None/Unknown 25%

Information Development 15%

Hardware 2%

Build Package 0%

Flight Software 58%
Results: MER software defects

Distribution of Types* by Build

*What kind of fix?
Results: *Deep Impact & Stardust*

- Extended ODC approach to development-phase SCRs (Software Change Reports)
  - Classified initial set of 121 critical Deep Impact SCRs written by Ball (with highest cause-corrective action/failure effect ratings)
- Extended ODC approach to contractor software
  - Classified 101 software problem reports written by Lockheed Martin during System/ATLO testing of Stardust.
Results: Deep Impact
Distribution of Trigger* by Phase

- Capability Invocation
- Command Execution
- Recovery
- HW/SW Interaction
- Start/Restart, Shutdown, Reboot

- Code
- CSC Test
- CSCI Test
- Design
- Integration
- Requirements Analysis
- Unit Test
- <<Note>>

*calyst
Results: **MER/Stardust**

Comparative Distribution of Triggers*

- **Hardware**
- **Unknown**
- **Workload & Stress**
- **SW Configuration**
- **Recovery**
- **HW Configuration**
- **HW-SW Interaction**
- **Inspection/Review**
- **Special Procedure**
- **Start/Restart**
- **Command Execution**
- **Capability Invocation**

More MER s/w defects involve h/w

Many Stardust defects found by late-phase inspection

Similar defect profiles

* *catalysts*
Results: MER/Stardust

Comparative Distribution of Types*

*What kind of fix?
Results: Lessons Learned

- 2 basic kinds of requirements discovery:
  - Discovery of new (previously unrecognized) requirements or requirements knowledge
  - Discovery of misunderstandings of (existing) requirements

- Reflected in ODC Target (what gets fixed) and ODC Type (nature of the fix):
  1. Software change (new requirement allocated to software)
  2. Procedural change (new requirement allocated to operational procedure)
  3. Document change (requirements confusion addressed via improved documentation)
  4. No change needed
Results: Examples

1. Incomplete requirements, resolved by change to software:
   New software requirement became evident: initial state of a component’s state machine must wait for the associated motor’s initial move to complete

2. Unexpected requirements interaction, resolved by changes to operational procedures:
   Software fault monitor issued redundant off commands from a particular state (correct but undesirable behavior). Corrective action was to prevent redundant commands procedurally by selecting limits that avoid that state in operations
Results: Examples

3. Requirements confusion, resolved by changes to documentation
   Testing personnel incorrectly thought heaters would stay on as software transitioned from pre-separation to Entry/Descent mode; clarified in documentation.

4. Requirements confusion, resolved without change
   Testers assumed commands issued when component was off would be rejected, but commands executed upon reboot. No fix needed; behavior correct.
Results: *Infusion*

- ODC selected as one of the 2004 NASA Research Infusion projects (ARC, T. Pressburger, Lead)
  - Antenna Beam Waveguide Retrofit project (JPL) (S. Morgan, Proj. Mgr)
- ODC selected as a candidate defect-analysis tool by JPL’s *Software Quality Improvement* task
- Have picked up use of ODC:
  - “Linking features to failures” (Garnett & Lesch, IV&V)
  - Low Temperature Microgravity Physics Facility (JPL); set up to use ODC but project cancelled
  - Common Operating Environment project (Defense Information Infrastructure) (JPL)
Results: Dissemination

- ODC for operational anomalies:
- ODC for testing anomalies:
  - the 4 mechanisms involved in requirements discovery during testing, *ICSE 2003* (Int’l Conf on S/W Eng)
- ODC for anomalies in testing & operations:
  - *IEEE Software*, March/April, 2004
  - Found same 4 mechanisms in operations as in testing, *RE 2003* (Int’l Conf on Requirements Eng); best experience paper
- ODC-based analysis:
  - Patterns of defect data, *SMC-IT 2003* (Space Mission Challenges)
  - Automated analysis of ODC defect data (T. Menzies) at *SEKE 2003* (Int’l Conf S/W Eng & Knowledge Eng)
Benefits for Moon/Mars Human Space Flight Missions

ODC can contribute to the success and safety of the human flight program by improved understanding of defects during development, testing and operations.

Sustained human exploration missions will require innovative defect management approaches that feed-forward defect data to related missions.
Benefits for Moon/Mars Human Space Flight Missions

Mission Challenges:
1. Sustained missions with dynamic defect profiles
2. Incremental and fleet missions
3. Very large amount of contractor software for integration & testing
4. Rapid evolution in technologies and knowledge

ODC Features:
1. ODC avoids "can't see the forest for the trees" overload
2. ODC supports product line approach
3. ODC provides development-through-operations defect management
4. ODC allows us to continually test our operational assumptions
Conclusion: ODC Strengths

High value of adoption
- Identifies problem patterns
- Multi-project ODC baseline provides guidance to future projects
- Can answer current project’s questions regarding defects

• “Smooth adoption curve”
  - High usability
  - Flexible visualization & browsing options
  - Acceptable level of effort; can use existing fields in existing problem-reporting system
  - Partial automation (project selectable)

• Extensive NASA Experience
  - ODC for development, testing, and operations phases
  - ODC for project, contractor software
Conclusion: ODC Strengths

- Quantitative foundation
  - Metrics for process improvement
  - Metrics for tracking project quality
  - Metrics for assessment of reused software

- Future focus
  - Equips us with a methodology to continue to learn as space-exploration missions and processes evolve