SRE.2: TBRMs & Integrated SRE

- Experience with existing approaches
- TBRMs: Tree-based reliability Models
- Integrated SRE using TBRMs & others
Overview

- Reliability: $\text{Prob}$(failure-free operations)
  - \textbf{time domain}: for a specific period.
    $\Rightarrow$ reliability growth models.
  - \textbf{input domain}: for a specific input set.
    $\Rightarrow$ repeated sampling models.

- A new integrated approach: TBRMs
  - tree-based reliability models (TBRMs)
  - both input/time domain information.
  - data driven/sensitive partitions.
  - method: tree-based modeling (TBM).
  - risk focusing and remedial actions.
  - details: AIC paper (Tian 1998)
Product Environment

• Large (medium-reliable) products:
  ▶ Commercial: RDBMS, compilers, software tools and computing environments.
  ▶ Telecommunication products too.
  ▶ Size: Up to millions of LOC.
  ▶ Widely distributed/large user population.
  ▶ No precise operational profile.
  ▶ Process: roughly waterfall.

• Overall testing:
  ▶ Long testing period (2 ~ 18 months).
  ▶ Different testing sub-phases.
  ▶ System testing focuses on reliability.
  ▶ Test-until-it-breaks commonly used.
  ▶ Staffing level variations.
  ▶ Code base stability.
Testing Environment

- Scenario-based testing.
  - Shifting focus: learning/dependency.
  - Functionality-based scenario classes:
    - randomized workload
    - progression: complexity & intensity $\uparrow$
    - defect fixing and related runs
    - division among testers.

- Specific reliability analysis issues:
  - Scenario-based $\sim$ random testing
    - due to parallelism and interleaving
  - Defect fixing effect:
    - no long-term dependency
    - short-term dependency $\Rightarrow$ grouping (later)
  - Uneven faults $\Rightarrow$ TBRMs
Needs and Constraints

- Need assessment and analysis:
  - Track test effort, progress and defect.
  - Reliability assessment and prediction.
  - Effective defect detection and removal.
  - Process and quality improvement.

- Environmental constraints:
  - Minimize cost & schedule risks.
  - Data availability and affordability.
  - Process refinement.
  - Maximize data utilization.

- Recommendation:
  new, evolutionary approach, with support.
Overall Solution

- Combine SRGMs and IDRMs into TBRMs.

- Analysis and control:
  - SRGMs (s/w rel. growth models).
  - TBRMs: tree-based reliability models.
  - Progress monitoring & exit criteria.

- Problem identification and correction:
  - Use of input domain information
    - IDRMs (input domain rel. models)
    - identify high risk areas
  - Automatic partitioning via TBRMs.
  - Remedial actions for improvement.
Applications: Overview

- Product coverage:
  - Commercial products from IBM.
  - Improvement over original process.
  - Evolutionary approach:
    1. individual techniques.
    2. integration and refinement.
  - Recent work with Nortel Networks.

- Scope of Engagement:
  - Data definition and collection.
  - Data visualization and analysis.
  - Test progress tracking.
  - Reliability tracking with SRGMs.
  - Reliability improvement with TBRMs.
Applications: Testing & Data

- Data and tracking:
  - Integration with schedule information.
  - Normalization effect.
  - Summary reports and visualization.
  - Consistency checking automation.

- Customer usage information gathering
  - Operational profile construction.

- Coverage and input-domain analysis:
  - Functionality/function/static/dynamic.
  - Different levels of coverage for different testing phases.
  - Focused coverage through TBRM.
SRGMs: Application Experience

- Time measurements: Fig.2 (Tian 1998)
  - calendar time.
  - execution time: Musa models.
  - logical time: runs, transactions, etc.

![Diagram showing cumulative testing days, cumulative workload or failures, cumulative transactions, cumulative execution minutes, cumulative runs, and cumulative failures.]

184 days, 453 runs, 1293047422 transactions, 835530 execution minutes, 130 failures.
SRGMs: Application Experience

- Model applicability and effectiveness:
  - calendar time models useless.
  - products A, B, and C: Fig.3 (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - exec. time models costly & sensitive.
  - product B Fig.6b (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - runs suitable for some products.
  - product B: Fig.6a (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - runs suitable for some products.
  - product D: Fig. 8a (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - runs suitable some products.
  - product D: Fig.8b (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - transactions for other products.
  - product E: Fig.9 (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - time measurement comparison
  - product E: Fig.5 (Tian 1998)
SRGMs: Application Experience

- Model applicability and effectiveness:
  - context sensitive modeling for sub-groups or sub-phases \( \Rightarrow \) TBRMs.
  - product B: Fig.7 (Tian 1998)
SRGM Conclusions

• Modeling result interpretation:
  ▶ Accuracy of models:
    – prediction: training & testing sets
  ▶ Product purity at exit.
  ▶ Bounded estimations: multiple models.
  ▶ Convergence of modeling results.

• Evolving to usage-based data/model:
  ▶ Assurance of homogeneity:
    – if ‘yes’, run-based data/model;
    – if ‘no’, transaction measurement.
  ▶ Suitable for input domain analysis.
  ▶ Also as cross validation for TBRMs.
Assessing Existing Approaches

- Time domain reliability analysis:
  - Customer perspective.
  - Overall assessment and prediction.
  - Ability to track reliability change.
  - Problem: how to improve reliability?

- Input domain reliability analysis:
  - Explicit operational profile.
  - Better input state definition.
  - Hard to handle change/evolution.
  - Problem: realistic reliability assessment and handling numerous data sets/partitions?
An Integrated Approach

- Combine strengths of the two.

- Using TBRM for individual modeling:
  - Input state: categorical information.
  - Each run as a data point.
  - Time cutoff for partitions too.
  - Data sensitive partitioning
    - Nelson models for subsets.

- Integrated reliability analyses:
  - TBRM: partitioned subset reliability.
  - Use both input and timing information.
  - Monitoring changes in trees.
  - Enhanced exit criteria.
  - SRGM: overall reliability near exit.
  - Integrate into the testing process.
TBM: Technique for Integration

• Basic ideas:
  ▶ TBM: tree-based models.
  ▶ Tree: nodes=data-set, edges=decision.
  ▶ Data: 1 response variable $Y$
    and $n$ predictor variables $X_1, \ldots, X_n$.
  ▶ Construction: recursive partitioning.
    (controlled growth vs growing & pruning)

• Usage and applications:
  ▶ Basic usage: $Y = Tree(X_1, \ldots, X_n)$
  ▶ Applicability: mixed-types of data.
  ▶ Past applications: social sciences
  ▶ In SE: risk identification by Selby & Porter,
    Tian & Troster, etc.

• Details: Tian/SQE book Ch.21.
TBRM Simple Example

- 1 categorical predictor and 1 response:
  - Binary grouping for partitioning
  - Example: Fig 10 (Tian 1998)
TBRM Simple Example

- 1 numerical predictor and 1 response:
  - Binary operator (≥) for partitioning
  - Example: Fig 15 (Tian 1998)

Legend:
- s = succ rate
- n = # of runs
- attr < cutoff
- attr > cutoff
TBRM Simple Example

- 1 categorical predictor and 1 response:
  - Interpretation as piecewise linear model
  - Example continued: Fig 14 (Tian 1998)
TBRM Example

- n mixed predictors and 1 response:
  - full TBRM
  - Example: Fig 11 (Tian 1998)
TBRM in Integrated Analysis

- Tree-based reliability models (TBRMs) using all information:
  - Input domain partitioning information.
  - Testing results.
  - Timing information.
  - Each run as a data point.

- Model construction:
  - Response: Result indicator.
    - 1 for success, 0 for failure.
      ⇒ Nelson model for subsets.
    - Mapping to failure rate or MTBF.
  - Predictor: Timing and input states.
    - Data sensitive partitioning.
    - Key factors affecting reliability.
    - Homogeneity of product reliability.
Using Integrated Analysis

- Interpretation of trees:
  - Predicted response: success rate.
  - (Nelson reliability estimate.)
  - Time predictor: reliability change.
  - State predictor: risk identification.

- Monitoring reliability change:
  - Change in predicted response.
  - Through tree structural change.

- Risk identification and remedies:
  - Identify high risk input state.
  - Additional analysis.
  - Enhanced test cases.
  - Remedies for components.
TBRMs in Integrated Analysis

- Treatment of product bundles:
  - TBRM for individual products.
  - Dynamic change w.r.t. process needs.
  - SRGM (& TBRM) for bundle near exit.

- Risk identification:
  - High risk input sub-domains.
  - Additional analysis for the identified.
  - Guide for remedial actions.

- Results interpretation:
  - Progression of trees & tree types.
  - Usage as exit criteria.
TBRMs at Different Times

- Fig 12a (Tian 1998): an early TBRM.
  - high-risk areas identified by input
  - early actions to improve reliability
TBRMs at Different Times

- Fig 12b (Tian 1998): a late TBRM.
  - high-risk areas ≈ early runs
  - uniformly reliable ⇒ ready for release
Cross Validation

- Consistency with macro models:
  \[\Rightarrow\] Effects on cost, schedule, quality.

- Validate with reliability growth models:
  \[\Rightarrow\] Trend of reliability growth.
  \[\Rightarrow\] Stability of failure arrivals.
  \[\Rightarrow\] Estimated reliability.
  \[\Rightarrow\] Product purity level at exit.

- Process changes & improvements:
  \[\Rightarrow\] Failure detection and fault removal.
  \[\Rightarrow\] Long term effect on development.

- Ultimate test: in-field problems.
TBRM Result Comparison

- Fig 22.6 (p.384): TBRMs used in D
  - better reliability growth in D
  - compare to A, B, and C (no TBRMs)
TBRM Result Comparison

- Table 22.3 (p.384):
  quantitative comparison with $\rho$

<table>
<thead>
<tr>
<th>Purification Level</th>
<th>Product</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum</td>
<td></td>
<td>0.715</td>
<td>0.527</td>
<td>0.542</td>
<td>0.990</td>
</tr>
<tr>
<td>median</td>
<td></td>
<td>0.653</td>
<td>0.525</td>
<td>0.447</td>
<td>0.940</td>
</tr>
<tr>
<td>minimum</td>
<td></td>
<td>0.578</td>
<td>0.520</td>
<td>0.351</td>
<td>0.939</td>
</tr>
</tbody>
</table>

Where: $\rho = \frac{\lambda_0 - \lambda_T}{\lambda_0} = 1 - \frac{\lambda_T}{\lambda_0}$

$\lambda_0$: failure rate at start of testing
$\lambda_T$: failure rate at end of testing
Integrated Approach: Implementation

- Modified testing process: Fig 18 (Tian 1998)
  - Additional link for data analysis.
  - Process change and remedial actions.
Integrated Approach: Implementation

- Tool support: Fig 20 (Tian 1998)
  - different types of tools
  - I/O and interconnection
Integrated Approach: Implementation

- Activities and Responsibilities:
  - Evolutionary, stepwise refinement.
  - Collaboration: project & quality orgs.
  - Experience factory prototype (Basili).

- Implementation:
  - Passive tracking and active guidance.
  - Periodic and event-triggered.
  - S/W tool support
Implementation Support

• Types of tool support:
  ▶ Data capturing
    – mostly existing logging tools
    – modified to capture new data
  ▶ Analysis and modeling
    – SMERFS modeling tool
    – S-PLUS and related programs
  ▶ Presentation/visualization and feedback
    – S-PLUS and Tree-Browser

• Implementation of tool support:
  ▶ Existing (IBM+others) tools: cost ↓
  ▶ New tools and utility programs
  ▶ Tool integration
    – loosely coupled suite of tools
    – connectors/utility programs
    – common depository: S-PLUS
Application Summary

- Tracking and input-domain analysis:
  - Effectiveness of visualization.
  - Problems with input-domain assessment.

- Time-domain analysis refinement:
  - Data normalization by runs/trans best.
  - Context sensitive modeling promising.

- Integrated approach using TBRM:
  - Guidance as well as assessment.
  - Risk focusing $\Rightarrow$ reliability improvement.
  - Progression of trees.
  - Usage as exit criteria.
  - Cross validation.
Future Directions

• Implementation and deployment:
  ▶ Data: automated data capturing.
  ▶ OP: evolutionary approach.
  ▶ Integration: analysis and improvement.
  ▶ Use in different industrial environments.

• Exploration and improvement:
  ▶ Customize time/transaction measurement.
  ▶ Early indicators/predictive modeling.
  ▶ Customer environment/OP refinement.
  ▶ Integrate to life-cycle quality models.
  ▶ Management and cost modeling.
  ▶ Refinement of modeling techniques.

• Continued research at SMU and collaboration with our industrial partners.