

# Software Reliability and Safety

## CSE 8317 — Fall 2007

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### **SRE.4: Applications & Frontiers**

- Non-traditional applications.
- Data treatment for better results
- Data clustering and DCRMs
- Research issues and improvement

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## Current SRE Assessment

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- Reliability assessment:
  - ▷ IDRMs and SRGMs (TBRMs too)
  - ▷ Key: data reflect reliability
  
- Reliability prediction: SRGMs
  - ▷ OP accuracy?
  - ▷ Data appropriate/meaningful?
  
- Reliability improvement:
  - ▷ TBRMs and other emerging approaches
  - ▷ Key: early risk identification
  
- More research needed.  
(Why we are working on related topics.)

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## SRE Applications

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- Traditional applications:
  - ▷ “medium-reliable” systems.
  - ▷ Telecommunication software/systems:
    - Musa/AT&T/Lucent, and others.
  - ▷ Operation systems and system software:
    - DEC/HP/IBM/etc.
  - ▷ Commercial software systems:
    - IBM examples in this class.
  - ▷ Other similar applications.
  
- New application domains:
  - ▷ Adapting existing models/techniques.
  - ▷ Data selection/treatment necessary?
  - ▷ New models/techniques needed?

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## Web Testing and SRE

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- SMU Project background:
  - ▷ NSF 0204345 and industrial partners
  - ▷ research team: Alaeddine, Nguyen, Shaddad, Kallepalli, Li, Ma, Rudraraju, Tian.
  - ▷ key publications: 2 TSE papers
    - (Kallepalli and Tian, 2001)
    - (Tian/Rudraraju/Li, 2004)
  
- Key activities and results:
  - ▷ Usage-based testing: UMMs
    - unified Markov models
    - details in Tian/SQE book: Ch.10.
  - ▷ Statistical web testing and SRE:
    - (Kallepalli and Tian, 2001)
  - ▷ Web SRE: time/activity measurement:
    - (Tian/Rudraraju/Li, 2004)
  - ▷ Web ODC: (Ma and Tian, 2007)

## Web Characteristics and QA

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- Web applications and QA:
  - ▷ Large, diverse, general population.
  - ▷ Document/information vs. computation.
  - ▷ Diverse usage patterns/environments.
  - ▷ Reliability one of the key concerns.
  
- Usage environment:
  - ▷ Traditional hardware/software env.
  - ▷ Network/middleware/server/browser/etc.
  - ▷ Layered structure.
  - ▷ Failure analysis necessary.
  
- SRE and statistical testing appropriate.

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## Web Failure, QA, and Reliability

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- Web failure: inability to deliver information or document required by a web user.
  
- Infrastructure failure
  - ▷ Host failure: hardware/OS.
  - ▷ Network failure: down/congested.
  - ▷ Browser failure: software problem.
  - ▷ Related hardware/software problems.
  - ▷ Existing hardware/software reliability
  
- Information source failure
  - ▷ Individual page problems
  - ▷ Overall reliability: focus here.
  
- User errors: beyond our control.

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## Web Logs and Usage/Reliability

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- Access and error logs: Information source for usage modeling and reliability analysis (Tian/Rudraraju/Li, 2004)
  
- Access log: hits
  - ▷ loading a HTML file
  - ▷ loading graphics etc.
  - ▷ but not operations using local cache
  - ▷ specific information recorded at server
  - ▷ sample entries: Table 1
  
- Error log: problems
  - ▷ sample entries: Table 2
  - ▷ problem type: Table 3
  - ▷ similar info and format

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## Error Logs and Reliability Analysis

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- Error logs
  - ▷ Detailed problem information
  - ▷ "failures" for reliability analysis
  - ▷ In conjunction with other measurements
  - ▷ When absent: use response code.
  
- Reliability analysis
  - ▷ Reliability by Nelson model
  - ▷ Mean-time-between-failures
$$\text{MTBF} = \frac{1}{f} \sum_i t_i$$
for usage time  $t_i$
  - ▷ MTBF when  $t_i$  not available
$$\text{MTBF} = \frac{n}{f}$$
  - ▷ Reliability growth using SRGMs (software reliability growth models)



## Case Studies

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- Site, information sources, and tools
  - ▷ Site: [www.seas.smu.edu](http://www.seas.smu.edu)
  - ▷ Information sources: access/error logs (Apache web server)
  - ▷ Analysis tools:
    - FastStat and Perl programs
  - ▷ Manual analysis also
  
- Cross-validation:
  - ▷ [www.kde.org](http://www.kde.org).
  - ▷ Different types of web site.
  - ▷ Heavier traffic.

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## Case Study: Error Analysis

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- General error analysis result:
  - ▷ Summary: Table 4
  - ▷ Types A through K, but two key types:
    - Type A: permission denied
    - Type E: file does not exist
  
- Further analysis of errors
  - ▷ Type A: may or may not be considered as failures
  - ▷ Type E: "failures"
  - ▷ Further analysis of Type E errors
  - ▷ Relating to usage information
  - ▷ Reliability analysis

## Case Study: Reliability Analysis

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- Error over time: Fig 1.
  - ▷ Ups and downs (calendar time)
  - ▷ Impact of traffic/workload
  - ▷ Conclusion: proper workload/usage measurement for reliability analysis
  
- Possible workload/usage measurements:
  - ▷ Hits: already done in (Kallepalli and Tian, 2001)
  - ▷ Bytes (some difficulties)
  - ▷ Sessions ( $\approx$  to data grouping)
  - ▷ Users (meaningful to service providers)
  
- Measurement results: Figs 3-7.

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## Case Study: Reliability Analysis

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- Overall reliability:
  - ▷ Relating failures to usage
    - errors vs workload measurements
  - ▷ Example plot: Fig 8
    - errors vs. bytes
  
- Reliability evaluation results:
  - ▷ Application of Nelson model.
  - ▷ Error rate: 0.0379 error/hit.
  - ▷ MTBF = 26.6
  - ▷ Reliability = 0.962
  - ▷ Results in other units possible
    - but need to be cautious.
  - ▷ Comparison: Table 5

## Case Study: Reliability Analysis

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- Reliability growth for statistical testing
  
- Hypothetical situation:
  - ▷ usage-based testing
  - ▷ immediate defect removal
  - ▷ studied over 26 days
  - ▷ calculated from error/access logs
  - ▷ computation: unique error sequence
  
- SRGM results:
  - ▷ GO model for errors vs. bytes: Fig. 10
  - ▷ Reliability growth: 74.8%  
(defect reduction)
  - ▷ Other results: Table 6.
  - ▷ Purification level  $\rho$   
(from SRE.3, and SQE Ch.22)

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## Case Study: Reliability Analysis

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- Cross validation using KDE data.
  
- Overall workload and reliability:
  - ▷ Profiles: Fig 11 (4 profiles)
  - ▷ Session profile: Fig 12 – two variations (2 hr vs. 15 min)
    - only 2 hrs used for SMU/SEAS
  - ▷ Hourly traffic: Fig 13.
  - ▷ Overall results: Table 7.
  - ▷ Similar results (better reliability)
  
- Reliability growth:
  - ▷ GO model for errors vs. bytes: Fig. 14
  - ▷  $\rho = 86.7\%$  to  $88.9\%$
  - ▷ consistency $\uparrow$  and reliability growth $\uparrow$

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## Web SRE Summary

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- What has been done?
  - ▷ Reliability assessment/prediction by analyzing both access and error logs
  - ▷ Case study to demonstrate viability and effectiveness
  
- SRE specific results:
  - ▷ Data and modeling from existing sources.
  - ▷ Good operational reliability assessment.
  - ▷ Reliability growth potential assessment.
  - ▷ 2 diverse web sites ⇒ generalization.
  - ▷ Future research: – change impact, risk identification, byte traffic measurement.

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## Data-Model Mismatch

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- Data-model mismatch:
  - ▷ Assumption mismatch.
  - ▷ Data appropriate?
    - ⇒ data selection and/or treatment
  - ▷ Model appropriate?
    - ⇒ choose alternative model
    - ⇒ develop new model
  - ▷ Research community: new models (but often impractical)
  - ▷ Industry: model/data selection/treatment
  - ▷ Examples from SRE.4
  
- Data treatment:
  - ▷ Censoring techniques
  - ▷ Grouping/clustering techniques



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## Data Treatment

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- Data censoring techniques:
  - ▷ Key idea: skip gaps in data
    - ⇒ censored data reflects usage
  - ▷ Technique: K.-Y. Cai, IEEE Trans. Reliability 46(1):69-75, 1997.
  
- Data compression:
  - ▷ Compression/expansion vs skipping
  - ▷ Basis: coverage
    - less likely to fail if tested
    - coverage as multiplier
  - ▷ Technique: M.-H. Chen et al, IEEE Trans. Reliability 50(2):165-170, 2001.
  
- Works with individual data points directly.

## Data Grouping

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- Need for data grouping:
  - ▷ Already grouped from applications:
    - hourly/daily/weekly/monthly data
    - data collection practicality
  - ▷ Local fluctuations
  - ▷ Data dependencies
  - ▷ Use PFC instead of TBF models
  
- Basis for data grouping:
  - ▷ External clock/time  
(most of the existing work)
  - ▷ Model (result) optimization
    - Schneidewind approach  
TSE 19(11):1095-1104, 11/1995
  - ▷ Data clustering

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## DCRM

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- General information/strategy:
  - ▷ Tian TSE 28(10):997-1007, 10/2002.
  - ▷ DCRM: DCRM1 + DCRM2  
data cluster based reliability models
  - ▷ Automatic clustering
  - ▷ DCRM1: direct usage
  - ▷ DCRM2: use with existing SRGMs  
(grouped data as input)
  
- Basic ideas: How?
  - ▷ Clustering of homogeneous runs.
  - ▷ Data driven/sensitive partitions.
  - ▷ Method: Tree-based modeling (TBM).

## The Case for Grouping

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- Scenario-based vs. random testing:
  - ▷ Parallelism/interleaving in testing.
  - ▷ Randomized workload.
  - ▷ Similar overall picture.
  - ▷  $\Rightarrow$  Data grouping.
  
- Defect fixing and run dependencies:
  - ▷ Strong short term dependency.
  - ▷ Lack of long term dependency.
  - ▷  $\Rightarrow$  Clustering.
  
- Develop DCRMs

## DCRM Construction

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- Clustering/grouping test runs:
  - ▷ By similar failure intensity.
  - ▷ Computation: Tree-based modeling (TBM) supported by S-PLUS.

- Generic procedure:
  - ▷ Identify period, runs, and time.
  - ▷ Failure intensity = failure / time,
  - ▷ Simple algebraic mean for segment:

$$\frac{\sum_{j=1}^{n_i} f_{ij}}{n_i} = \frac{f_i}{n_i} = \lambda_i$$

- ▷ Weighted average for segment:

$$\frac{\sum_{j, l_i < d_j \leq u_i} t_j \lambda_j}{\sum_{j, l_i < d_j \leq u_i} t_j} = \frac{\sum_{j, l_i < d_j \leq u_i} f_j}{\sum_{j, l_i < d_j \leq u_i} t_j} = \frac{F_i}{T_i} = \Lambda_i$$

- ▷ Other: as special cases of above.

## Model Usage and Performance

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- Direct usage: DCRM1
  - ▷ Reliability for each segment.
  - ▷ Overall trend assessment.
  - ▷ Current reliability: last segment.
  - ▷ Prediction: extrapolation.
  - ▷ Risk/anomaly identification.
  
- DCRM1 performance:
  - ▷ Goodness-of-fit:  $R^2$ 
    - 304 vs. 6329 for Goel-Okumoto.
  - ▷ Prediction comparison:
    - use training and testing sets.
    - linear extrapolation.
    - good short term results
  - ▷ Key advantage: early/wide applicability

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## DCRMs vs Other Models

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- DCRM1 vs IDRMs:
  - ▷ Partition by failure intensity in runs
    - similar to Nelson model.
  - ▷ Partition by general failure intensity
    - similar to Brown-Lipow model.
  
- DCRM1 vs SRGMs:
  - ▷ Constant  $\lambda$  for given period
    - similar to Jelinski-Moranda model.
  - ▷ But variable steps in consecutive steps
    - similar to Littlewood-Verrall model.
  - ▷ Non-function form for progression of  $\lambda$ 's
  
- PFC-SRGMs: used in DCRM2.

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## DCRM2

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- DCRM2: SRGMs with grouped data (each segment as a data point)
  
- Choosing SRGMs for DCRM2:
  - ▷ Only PFC (FC) models usage
  - ▷ NHPP choices:
    - Goel-Okumoto (GO)
    - Musa-Okumoto (MO, log Poisson)
    - Schneidewind and data req.
    - S-shaped as descriptive model
  - ▷ GO and MO choices
  
- More about GO and MO choices:
  - ▷ Lower/upper bound on estimates
  - ▷ Past experience at IBM
  - ▷ Empirical data elsewhere



## DCRM Performance

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- Product and comparison points:
  - ▷ Products E (and D) from IBM
  - ▷ E: last 8 weeks
    - 7 point comparison for DCRM2
  - ▷ DCRM1,  
GO, MO, DCRM2.GO, DCRM2.MO
  
- Applicability:
  - ▷ DCRM1 clearly superior
  - ▷ Others about equal
  
- Goodness-of-fit:
  - ▷ DCRM1 clearly superior
  - ▷ Others about equal
  - ▷ Caution: use more important

## DCRM Performance

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- Reliability assessment:
  - ▷ DCRM1 not as stable but available early
  - ▷ Convergence of others
  - ▷ DCRM2 provide tighter bound  
(more stable also, see prediction)
  
- Reliability prediction:
  - ▷ DCRM1 only for short term  
(mixed results)
    - only one available early
  - ▷ Prediction accuracy tables
  - ▷ Direct comparison graphs
  - ▷ Conclusion: DCRM2 better
  
- Model stability: DCRM2 better

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## DCRM Summary

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- Easily satisfiable assumptions:
  - ▷ Rough operational profiles.
  - ▷ No long term dependencies
    - but short term dependencies
  - ▷ Failure intensity clusters.
  
- Implementation and applications:
  - ▷ Model construction: S-PLUS.
  - ▷ Practical applications.
  - ▷ Better/wider applicability.
  - ▷ Robust/stable results.
  - ▷ Further studies underway.

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## Other Data/Models

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- Trend analysis:
  - ▷ Qualitative/visual inspection:
    - curvature (super-/sub-additive)
  - ▷ Quantitative analysis.
  - ▷ Avoid meaningless modeling results.
  
- Other data/models:
  - ▷ Reliability simulation:
    - especially for mixed h/w-s/w systems
  - ▷ Composite models.
  - ▷ Fault seeding technique.
  - ▷ General models for correlated data:
    - Goceva-Popstojanova and Trivedi, IEEE Trans. Reliability, 49(1):37-48, 3/2000.
  - ▷ etc., Lyu book.

## Improvement Strategies

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- Traditional models/techniques:
  - ▷ Assessment/prediction focus.
  - ▷ Limited used in improvement.
  - ▷ Testing/QA as semi-separate.
  - ▷ (assessment in Module IV)
  
- TBRM and extensions:
  - ▷ TBRMs for risk identification.
  - ▷ Focused improvement during testing.
  - ▷ Extension to other phases:
    - analyze other (e.g., inspection) data
    - reliability composition

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## Other Research Topics

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- Linking SRE with metrics/analysis.
  - ▷ Musa prescriptive models refinement.
  - ▷ Metrics-SRE: still separate
    - risk (problem-prone) identification
  - ▷ Quantitative linkage?
  
- Reliability composition:
  - ▷ Small scale: Hamlet/Mason/Woit work.
  - ▷ RE to requirement: Smidts work.
  - ▷ Work at SMU: OP-mapping, fault-injection, embedded systems.
  
- Reliability optimization.
  - ▷ Other factors: cost, schedule, etc.
  - ▷ Lyu/Rangarajan/van Moorsel work.