Software Quality Engineering

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Testing, Quality Assurance, and Quantiable Improvement
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Chapter 22. Software Reliability Engineering

- Concepts and Approaches
- Existing Approaches: SRGMs & IDRMs
- Assessment & Improvement with TBRMs
- SRE Perspectives

What Is SRE

- Reliability: Probability of failure-free operation for a specific time period or input set under a specific environment
    - Failure: behavioral deviations
    - Time: how to measure?
    - Input state characterization
    - Environment: OP
- Software reliability engineering:
    - Engineering (applied science) discipline
    - Measure, predict, manage reliability
    - Statistical modeling
    - Customer perspective:
        - failures vs. faults
        - meaningful time vs. development days
        - customer operational profile

Assumption: SRE and OP

- Assumption 1: OP, to ensure software reliability from a user's perspective.
- OP: Operational Profile
    - Quantitative characterization of the way a (software) system will be used.
    - Test case generation/selection/execution
    - Realistic assessment

    - Predictions (minimize discontinuity)
- OP topics in SQE book:
    - Chapter 8: Musa's OP
        - flat list with probabilities
        - tree-structured OP
        - dev. procedures: Musa-1/Musa-2
    - Chapter 10: Markov chains and UMMs (unified Markov models)

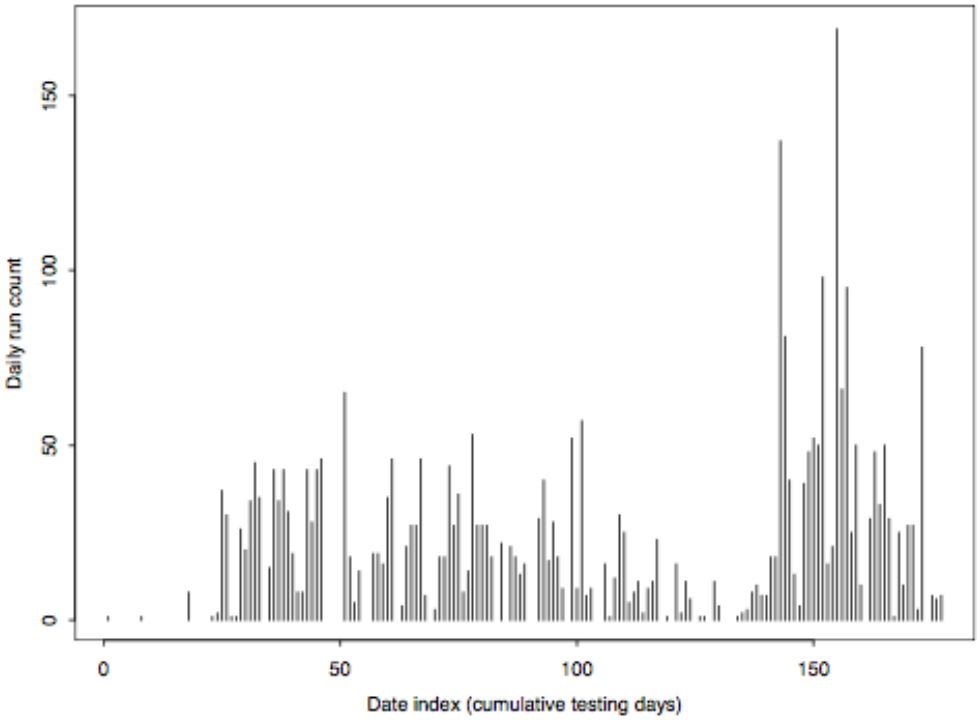
Other Assumptions in Context

- Assumption 2: Randomized testing
    - Independent failure intervals/observations
    - Approximation in large software systems
    - Adjustment for non-random testing

    => new models or data treatments
- Assumption 3: Failure-fault relation
    - Failure probability ~ # faults
    - Exposure through OP-based testing
    - Possible adjustment?
    - Statistical validity for large s/w systems
- Assumption 4: time-reliability relation
    - time measurement in SRGMs
    - usage-dependent vs. usage-independent
    - proper choice under specific env.
- Usage-independent time measurement:
    - calendar/wall-clock time
    - only if stable or constant workload
- Usage-dependent time measurement:
    - for systems with uneven workload
    - execution time { Musa's models
    - alternatives: runs, transactions, etc.

Workload for Products D

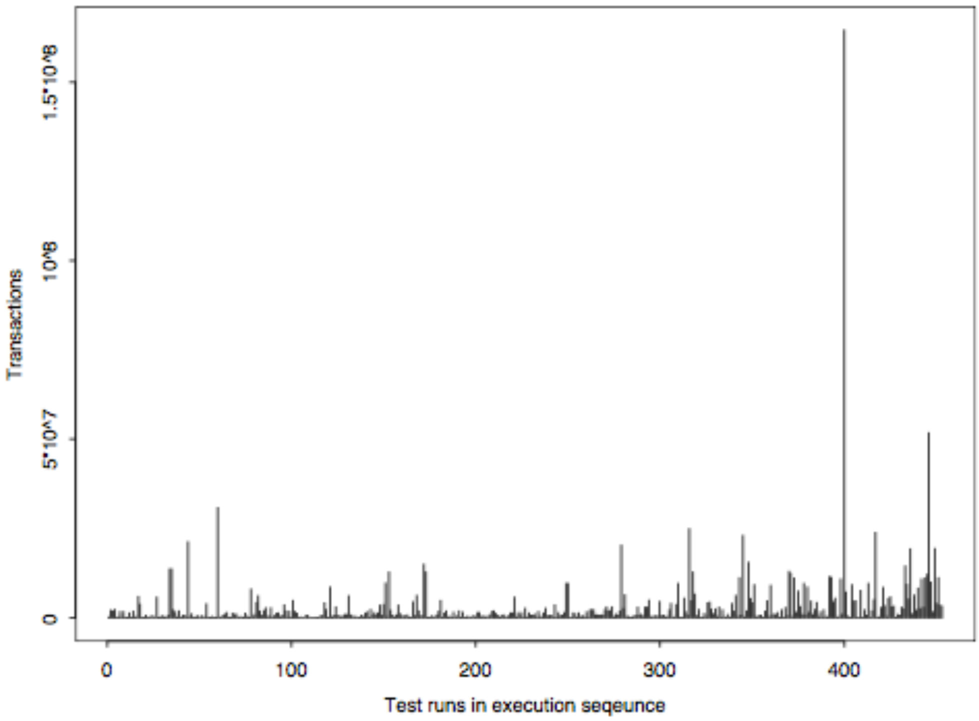
- Fig 22.1 (p.374): IBM product D workload



- number of test runs for each day
- wide variability
- need usage-dependent time measurement
  - number of runs used

Workload for Products E

- Fig 22.2 (p.375): IBM product E workload



  - number of transactions for each run
  - again, wide variability
  - need usage-dependent time measurement
    - number of transactions used

Input Domain Reliability Models

- IDRMs: Current reliability snapshot based on observed testing data of n samples.
- Assessment of current reliability.
- Prediction of future reliability

  (limited prediction due to snapshot)
- Management and improvement
  - As acceptance criteria.
  - Risk identification and followups:
    - reliability for input subsets
    - remedies for problematic areas
    - preventive actions for other areas

Nelson's IDRM

- Nelson Model:

    - Running for a sample of n inputs.
    - Randomly selected from set E:

      E = { Ei : i = 1; 2; ... ; N }

    - Sampling probability vector:

      { Pi : i = 1; 2; ... ; N }

    - fPig: Operational profile.

    - Number of failures: f .
    - Estimated reliability:

      R = 1 - r = 1 - f/n = (n - f)/n

    - Failure rate: r.

- Repeated sampling without fixing.

IDRM Applications

- Nelson model for a large s/w system

    - succ. segments: Table 22.1 (p.376)

Segment	rn Range	$\hat{R}_i$	$\hat{\lambda}_i$
1	$0 < rn \le 137$	0.241	0.759
2	$137 < rn \le 309$	0.558	0.442
3	$309 < rn \le 519$	0.176	0.824
4	$519 < rn \le 1487$	0.454	0.546
5	$1487 < rn \le 1850$	0.730	0.270
6	$1850 < rn \le 3331$	0.930	0.070

- Nelson model for web applications

    - daily error rates: Table 22.2 (p.377)

Daily Error Rate	min	max	mean	std dev	rse
errors /hits	0.0287	0.0466	0.0379	0.00480	0.126
errors /day	501	1582	1101	312	0.283

Other IDRMs and Applications

- Brown-Lipow model:
  - explicit input state distribution.
  - known probability for sub-domains Ei
  - fi failures for ni runs from subdomain Ei

$$R = 1 - \sum_{i=1}^{N} \frac{f_i}{n_i} P(E_i)$$

  - would be the same as Nelson model for representative sampling
- IDRM applications
  - overall reliability at acceptance testing
  - reliability snapshots over time: in Nelson model examples earlier
  - reliability for input subsets: in TBRMs

Time Domain Measures and Models

- Reliability measurement
  - Reliability: time & probability
  - Result: failure vs. success
  - Time/input measurement
  - Failure intensity (rate): alternative
  - MTBF/MTTF: summary measure
- S/W reliability growth models (SRGMs):
  - Reliability growth due to defect removal based on observed testing data.
  - Reliability-fault relations
  - Exposure assumptions
  - Data: time-between-failure (TBF) vs. period-failure-count (PFC) models

Basic Functions (Time Domain)

- Failure distribution functions:
  - F (t): cumulative distribution function

    (cdf) for failure over time
  - f (t): prob. density function (pdf)

    f (t) = F'(t)
- Reliability-related functions:
  - Reliability functio R(t) = 1 - F (t)

R(t) = P (T >= t) = P (no failure by t)

- Hazard function/rate/intensity

$$z(t)\Delta t = P\{t < T < t + \Delta t | T > t\}$$

- Jelinski-Moranda (de-eutrophication) model:

$$z_i = \phi(N - (i - 1))$$

Other Basic Definitions

- MTBF, MTTF, and reliability
  - Mean time to failure (MTTF)

$$\mathrm{MTTF} = \int_0^\infty t f(t) dt = \int_0^\infty R(t) dt$$

  - Mean time between failures (MTBF)

    = MTTF for memoryless process

    - similarly defined
  - good summary measure of reliability
- Reliability-hazard relation:

$$R(t) = e^{-\int_0^t z(x)dx}$$

$$z(t) = \frac{f(t)}{1 - F(t)} = \frac{f(t)}{R(t)}$$

Other Basic Functions

- Overall failure arrival process:

  (as compared to individual failures)
- NHPP (non-homogeneous Poisson process):
  - Most commonly used for modeling
  - Probability of n failures in [0; t]:

$$P(N(t)=n)=\frac{m(t)^n}{n!}e^{-m(t)}$$

- m(t): mean function
- Failure rate/intensity >=(t):

$$\lambda(t)=m'(t)=\frac{dm(t)}{dt}$$

- Other processes: Binomial, etc.

Commonly Used NHPP Models

- Goel-Okumoto model

$$m(t)=N(1-e^{-bt})$$

  - N : estimated number of defects
  - b: model curvature
- S-shaped model:

$$m(t)=N(1-(1+bt)e^{-bt})$$

  - allow for slow start
  - may be more descriptive
- Musa-Okumoto execution time model:

$$m(\tau)=\frac{1}{\theta}\log(\lambda_0\theta\tau+1)$$

  - emphasis: execution time T

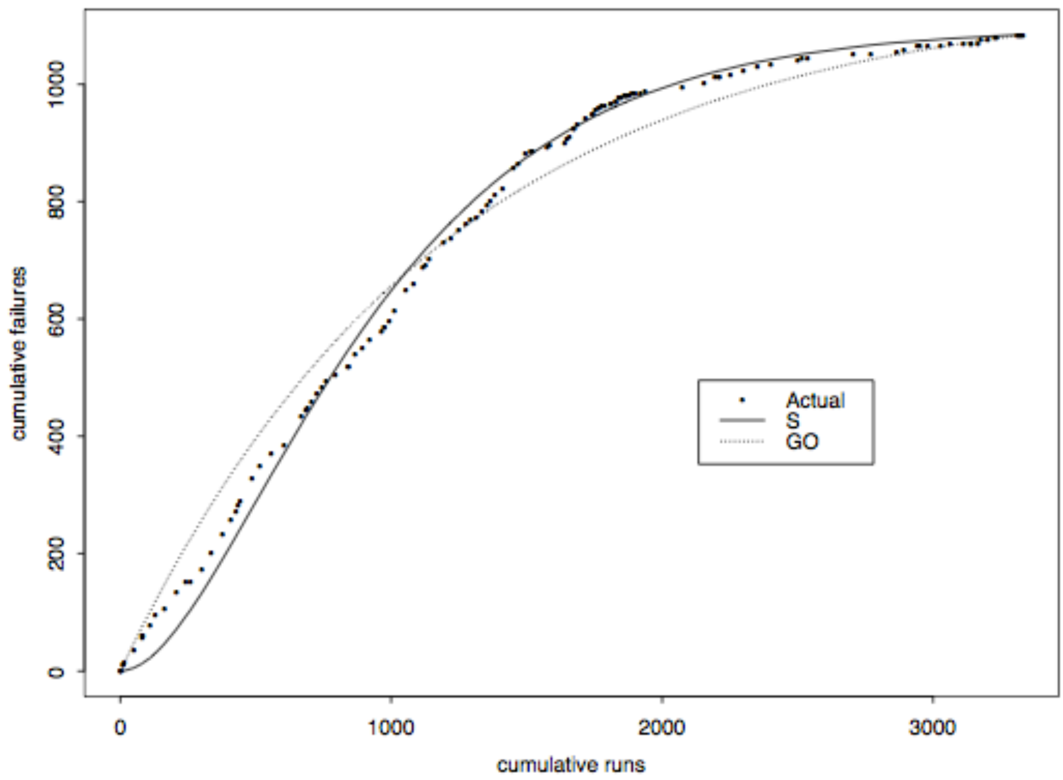
SRGM Applications

- Assessment of current reliability
- Prediction of future reliability and resource to reach reliability goals
- Management and improvement
  - Reliability goals as exit criteria

- Resource allocation (time/distribution)
- Risk identification and followups:
    - reliability (growth) of different areas
    - remedies for problematic areas
    - preventive actions for other areas

SRGM Application Example

- SRGM example: Fig. 22.3 (p.380)



- IBM product D, number of runs as workload
- Goel-Okumoto (GO) and S-shape SRGMs

Assessing Existing Approaches

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

- Explicit operational profile.
- Better input state definition.
- Hard to handle change/evolution.
- Issues: sampling and practicality.
- Problem: realistic reliability assessment?

TBRMs: An Integrated Approach

- Combine strengths of the two.
- TBRM for reliability modeling:
  - Input state: categorical information.
  - Each run as a data point.
  - Time cutoff for partitions.
  - Data sensitive partitioning

    => Nelson models for subsets.
- Using TBRMs:
  - Reliability for partitioned subsets.
  - Use both input and timing information.
  - Monitoring changes in trees.
  - Enhanced exit criteria.
  - Integrate into the testing process.

TBRMs

- Tree-based reliability models (TBRMs): TBM using all information.
- Response: Result indicator rij.
  - rij = 1 for success, 0 for failure.
  - Nelson model for subsets:

$$s_i = \frac{1}{n_i}\sum_{j=1}^{n_i} r_{ij} = \frac{n_i - f_i}{n_i} = \hat{R}_i \qquad \text{or}$$

$$s_i = \frac{\sum_{j=1}^{n_i} t_{ij} s_{ij}}{\sum_{j=1}^{n_i} t_j} = \frac{\sum_{j=1}^{n_i} r_{ij}}{\sum_{j=1}^{n_i} t_j} = \frac{S_i}{T_i} = \hat{R}_i.$$

- Predictors: Timing and input states.
  - Data sensitive partitioning.
  - Key factors affecting reliability.

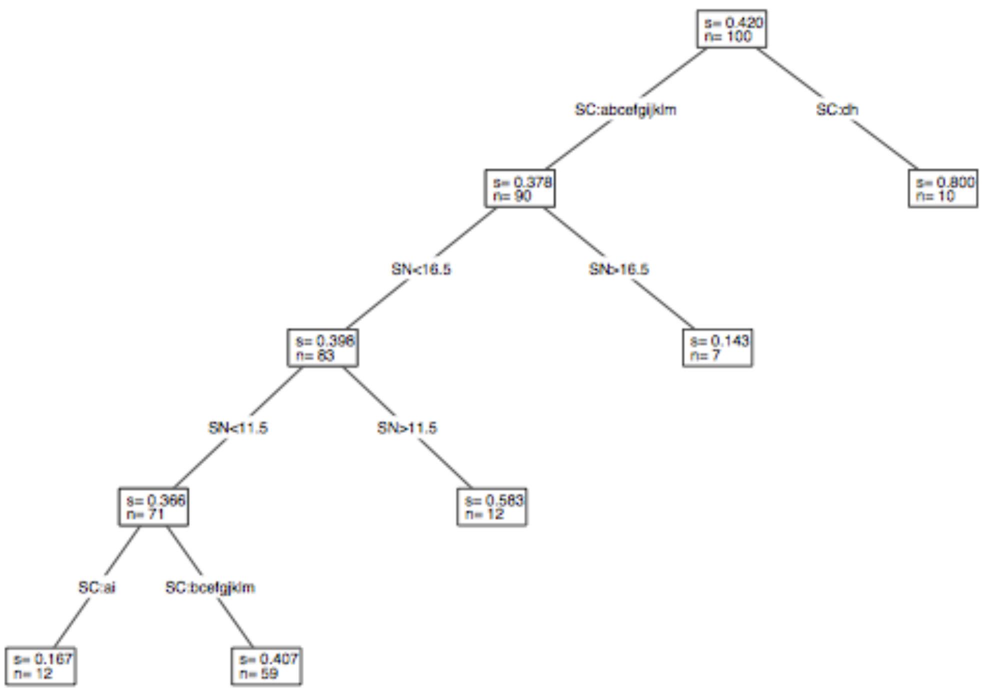
TBRMs: Interpretation & Usage

- Interpretation of trees:
  - Predicted response: success rate.

    (Nelson reliability estimate.)
  - Time predictor: reliability change.
  - State predictor: risk identification.
- Change monitoring and risk identification:
  - Change in predicted response.
  - Through tree structural change.
  - Identify high risk input state.
  - Additional analyses often necessary.
  - Enhanced test cases or components.

TBRMs at Different Times

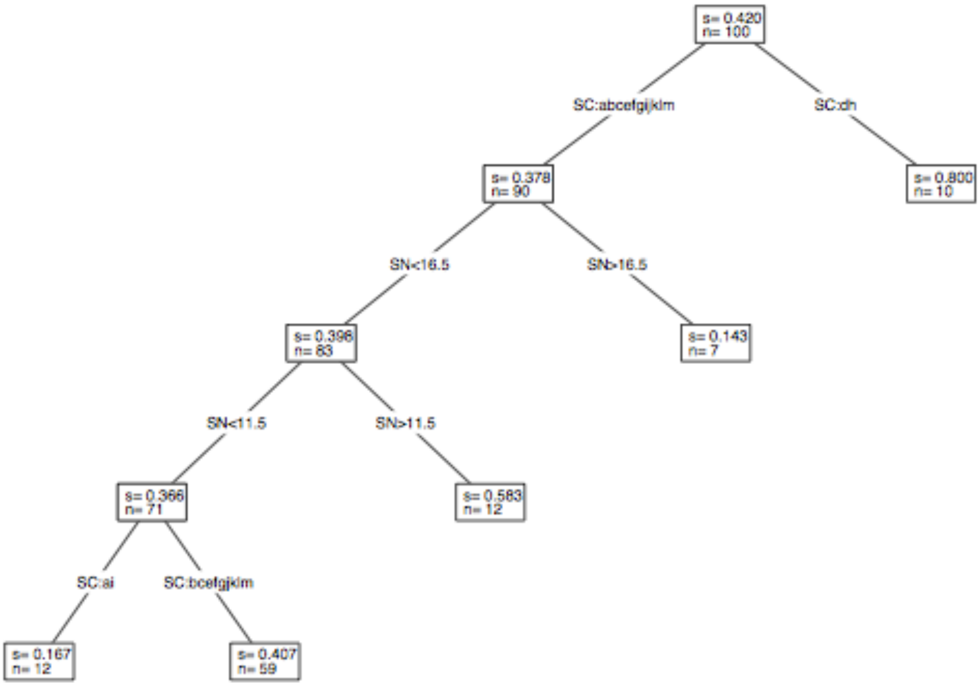
- Fig 22.4 (p.383): an early TBRM.



  - high-risk areas identified by input
  - early actions to improve reliability

TBRMs at Different Times

- Fig 22.5 (p.383): a late TBRM.



  - high-risk areas ~= early runs
  - uniformly reliable => ready for release

TBRM Impact

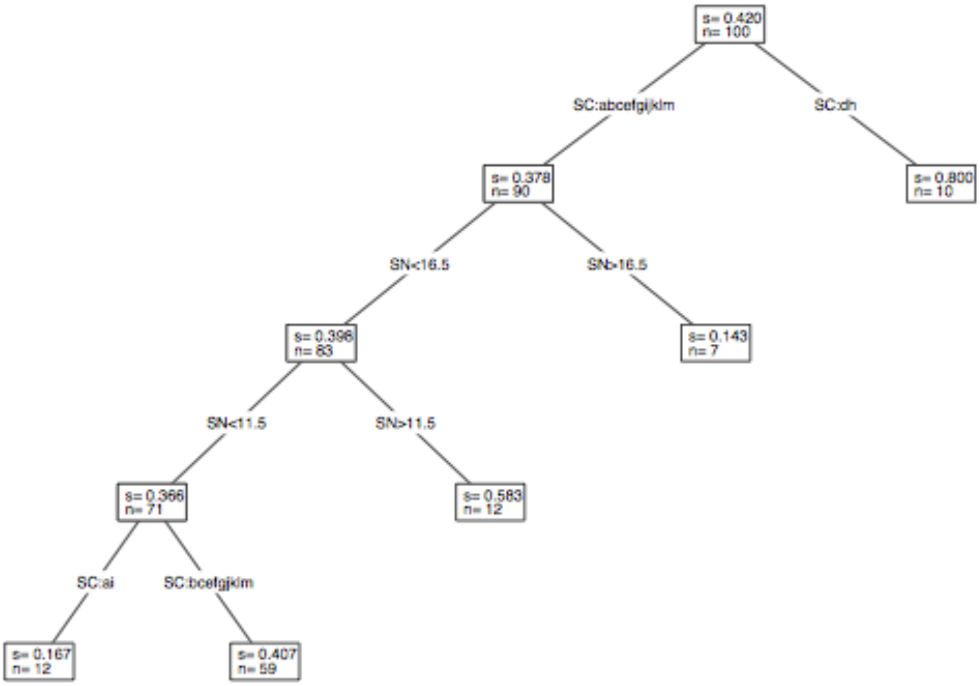
- Evaluation/validation with SRGMs:
  - Trend of reliability growth.
  - Stability of failure arrivals.
  - Estimated reliability: see below
- Quantitative impact evaluation:
  - Product purity level (cid:26) at exit:

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

- Important: deployment
  - all successor products at IBM

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 p

Purification Level ρ	Product A	B	C	D
maximum	0.715	0.527	0.542	0.990
median	0.653	0.525	0.447	0.940
minimum	0.578	0.520	0.351	0.939

Where:

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

λ_0: failure rate at start of testing
λ_T: failure rate at end of testing

Integrated Approach: Implementation

- Modified testing process:
    - Additional link for data analysis.
    - Process change and remedial actions.
- 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 tools: minimize cost
        - internal as well as external tools
    - New tools and utility programs
    - Tool integration
        - loosely coupled suite of tools
        - connectors/utility programs
    - Overall strategy: Chapter 18 (Section 18.4)

SRE Perspectives

- New models and applications
    - Expand from "medium-reliable" systems.
    - New models for new application domains.
    - Data selection/treatment
- Reliability improvement

    - Followup to TBRMs
    - Predictive (early!) modeling for risk identification and management
- Other SRE frontiers:
    - Coverage/testing and reliability
    - Reliability composition and maximization