“Self-Healing” Softening Precision to avoid Brittleness

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What do I mean by “Self Healing”?

- “Self-healing” means to me …

  … adaptive system change that improves quality of delivered service and provides resilience to perturbation

- But …
  - Health is in the eye of the beholder
    - Exact requirement varies among users and different times
    - Likewise the tolerance for degraded service
    - Most users are inarticulate about exact needs
  - Must a system be broken in order to invoke the mechanisms provide improvement?
    - Must you be sick before you can benefit from healing?

What sort of healing?

- Local
  - Fine-grained architectural reactions to local conditions
    - Replacement, tuning, rebalancing
  - Design strategies for robustness / continual improvement
- Incremental
  - Independent healing for different properties
  - Properties that can change smoothly
- Threshold-free (don't obsess about the sick / well distinction)
  - But with reference criterion or identified properties
  - Emphasis on improvement, not good / bad transitions
  - Scalable dependability – appropriate to need

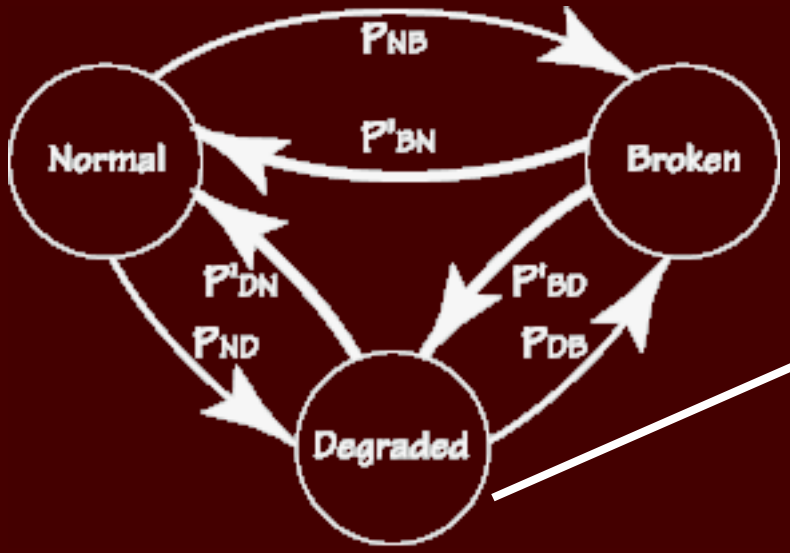
Related ideas

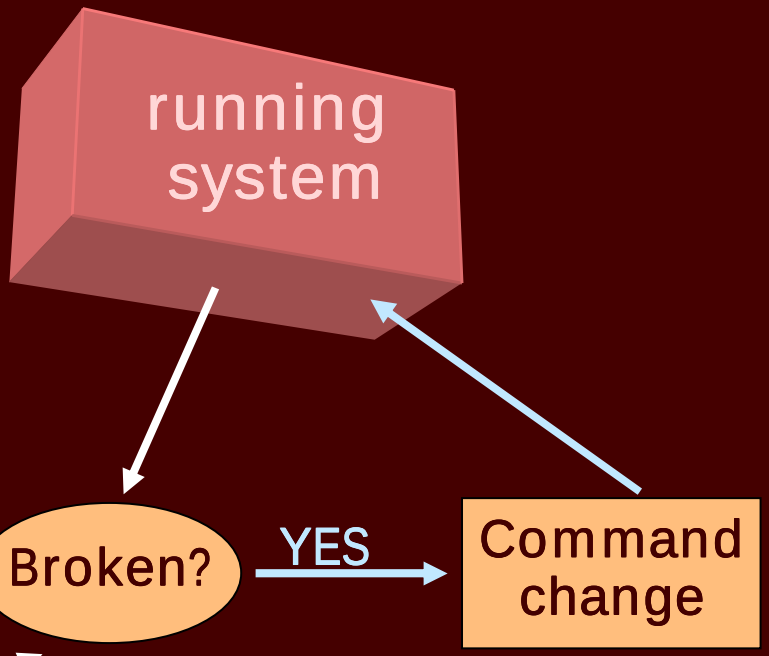
- cf D. Wile
  - Perturbation tolerance
  - Autonomic (instinctive) response
    - but here, not wired in as component-specific technique
- cf S. Gustavsson
  - Self-stabilization, eventual consistency
  - Global properties arise from localized action

Reactive Fault Tolerance

Normal

Fault tolerant





Problems

- Cost of specification
  - External specifications are too complex and costly to document completely
  - Diverting resources to internal distinctions seems counterproductive
- User-centered requirements
  - Different users have different thresholds for health
    - And different thresholds and different times
    - But often they cannot describe their thresholds precisely!
- Independence of mechanism from state
  - Systems often invoke the same healing actions in different states

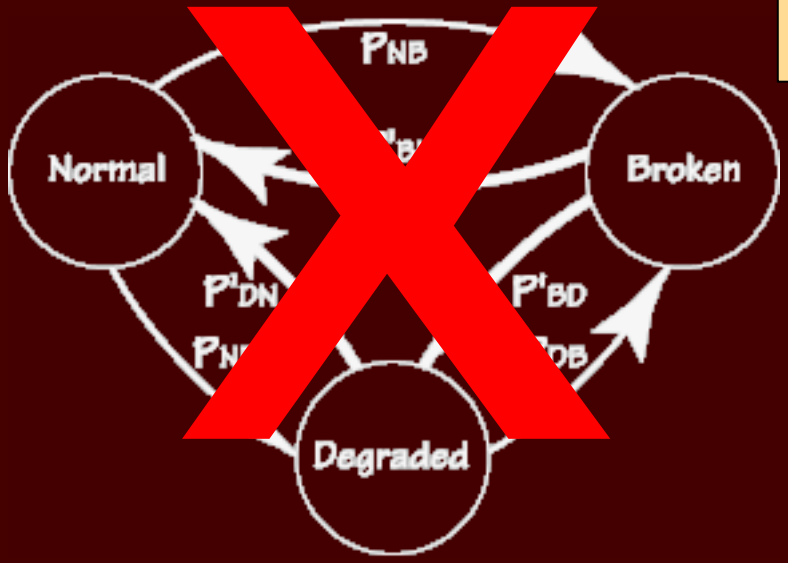
Idea: *Homeostasis*

- Instead of distinguishing "good" and "bad" states, react to ***all*** change in a way that sustains a property
- Analogy: biological and ecological systems
- Examples
  - Background maintenance (garbage collection)
  - Dynamic resource selection (Internet packet routing)
  - Slack, excess capacity (service capacity)
- Advantages
  - Techniques operate over a wide range of performance
  - Performance improves independent of health status
  - Does not require precise distinctions between internal states, freeing that effort for other aspects of design

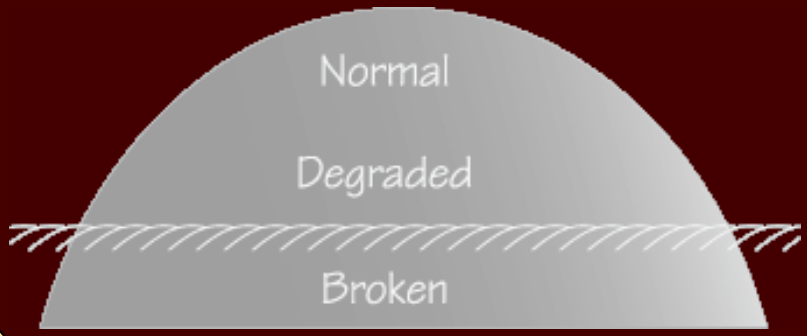
Reaction vs *Homeostasis*

Normal

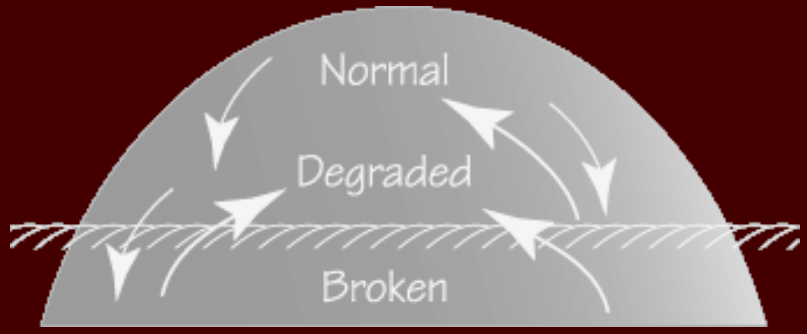
Fault tolerant



States -> Gradients

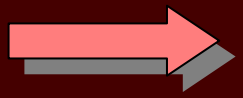


Fault tolerant



Special case: homeostasis via slack

- Simon's examples include excess capacity
  - e.g., inventory level sufficient to hide supply chain delay
- Queueing theory (Poisson arrivals)
  - As arrival rate approaches service time, wait infinity
- Fragility of tight coupling
  - Tightly-coupled systems have domino failures
  - Tight coupling often arises from optimization
- Safety factors
  - Civil engineers routinely overdesign by factor of 2-3



- Slack can provide mechanism-free homeostasis
  - Especially for transient perturbations

Cost-effectiveness of System Slack

- Excess capacity incurs system cost
- But so does reactive self-healing
  - Analysis
  - Monitoring
  - Healing / recovery / adaptation
  - Capacity to support reaction mechanisms
  - Reliability issues of mechanism
- Both (can) provide benefits, sometimes comparable
- Challenge is
  - compare costs for comparable benefit
  - establish comparative value when benefits differ

Realizing Homeostasis: Design rather than Mechanism

Getting beyond the specific examples

- Incremental update / consistency maintenance
  - Background garbage collection
  - Consistency propagation
- Dynamic resource selection (vs pre-bound decision)
  - Internet packet routing
  - Load balancing
- Safety factors, excess capacity, slack
  - Processing capacity instead of queue lengths
  - Mirror sites on Internet
  - Faster-than-necessary control cycle allows dropouts

Expand concept of “self-healing” to include health maintenance

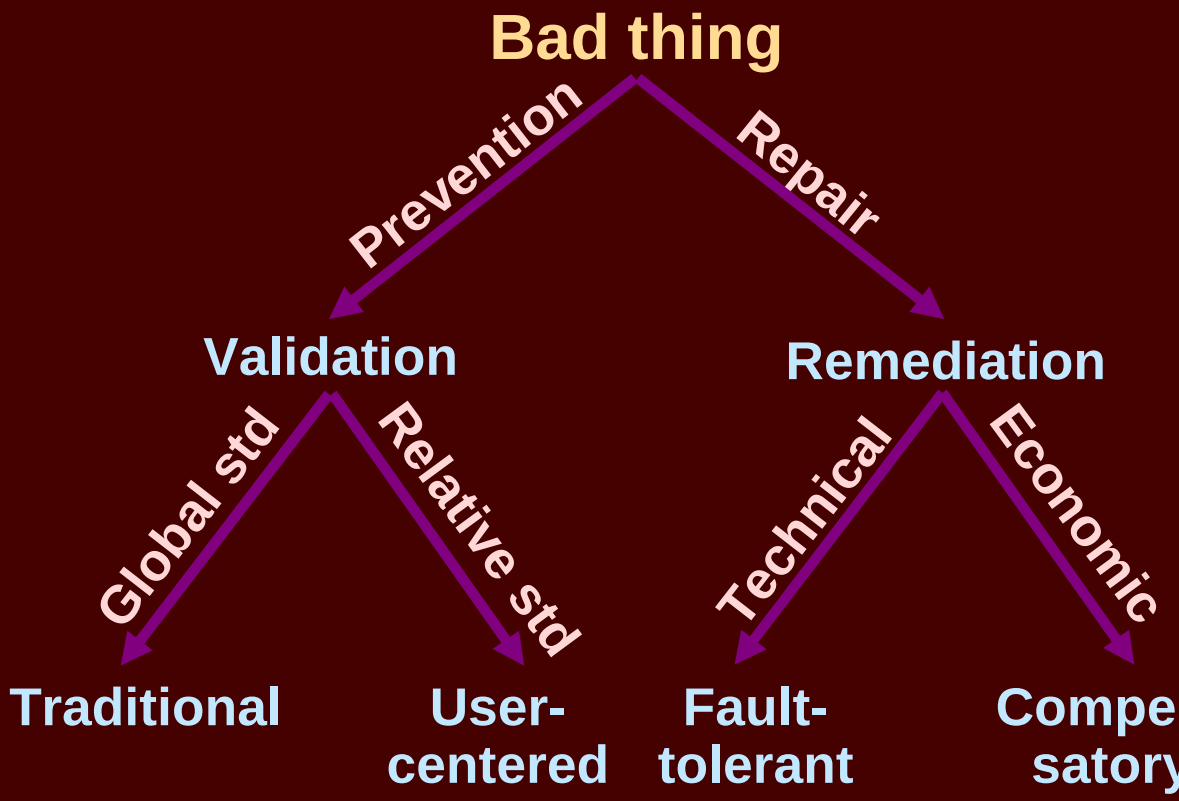
- Don’t require precise distinctions between healthy and unhealthy operating states

Maintain health by making normal operation sustain performance (homeostasis)

- Generalize from examples of homeostasis to find broad design principles

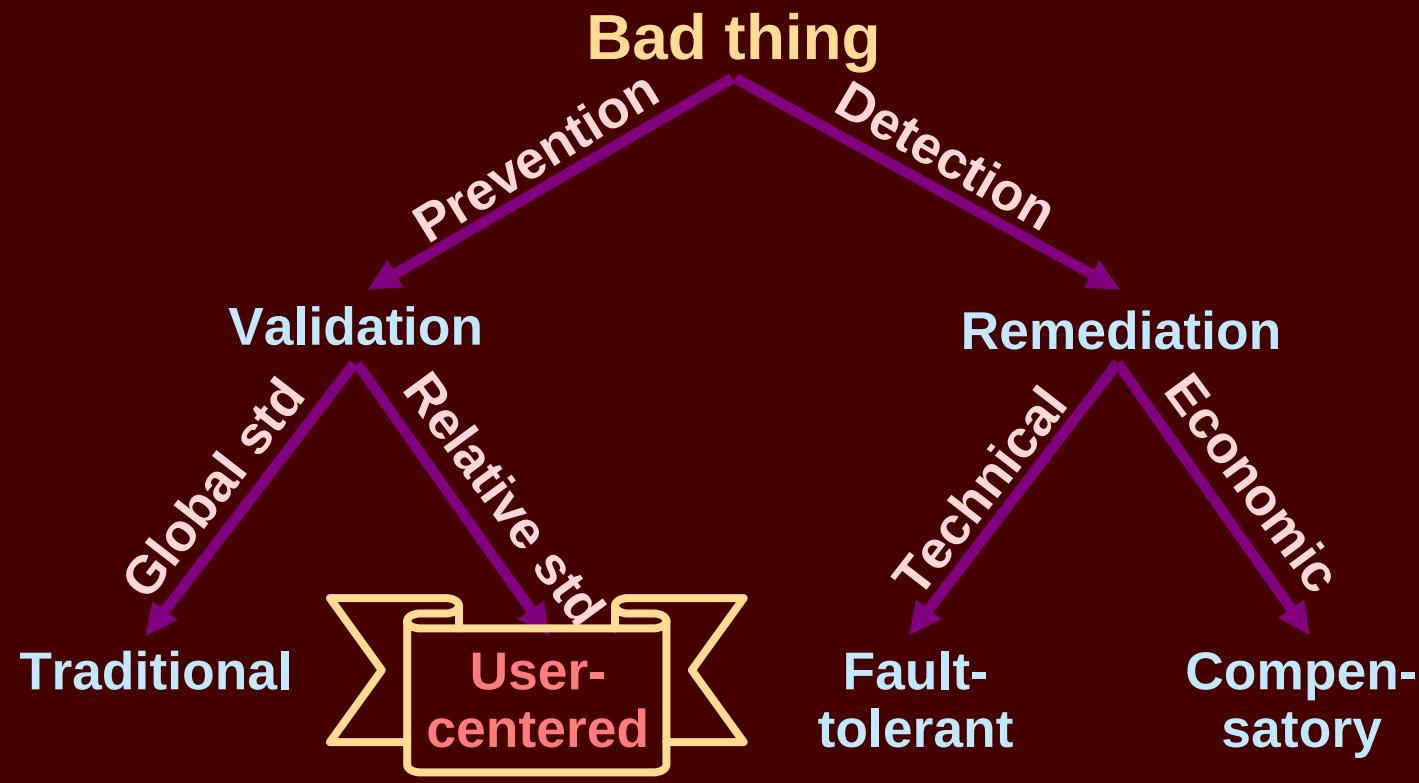
BEHOLD, WE HAVE SIGNAL

Ways to deal with failure



- Traditional: prevent through careful development, analysis
- User centered: set criteria for proper operation to reflect user needs
- Fault tolerant: repair failures as they occur
- Compensatory: provide financial compensation

Ways to deal with failure



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Security technology *portfolio selection*

- Different sites have different security issues
- Elicit concerns about threats and relative priorities with multi-attribute decision techniques
  - converts subjective comparisons to quantitative values
- Associate threat analysis with cost of successful attack and countermeasures available in the market
  - Consider cost-effectiveness and defense in depth
- Iterate, using sensitivity analysis and multiattribute techniques to refine recommendations
  - Get better understanding as well as recommendation
- Shawn Butler (finishing PhD this year)
  - Papers in ICSE 2002, CERIAS 2002

Utility-based Adaptive Configuration

- Mobile systems are resource-limited
  - Processor power, bandwidth, battery life, storage capacity, media fidelity, user distraction, …
- Users require different capabilities at different times
  - Editing, email, viewing movies, mapping, …
  - Dynamic preferences for quantity and quality of service
- Abstract capabilities can be provided by different combinations of services
  - Specific editors, browsers, mailers, players, …
- Use utility theory and linear/integer programming to find best set and configuration of services
- Vahe Poladian (2nd year PhD student)

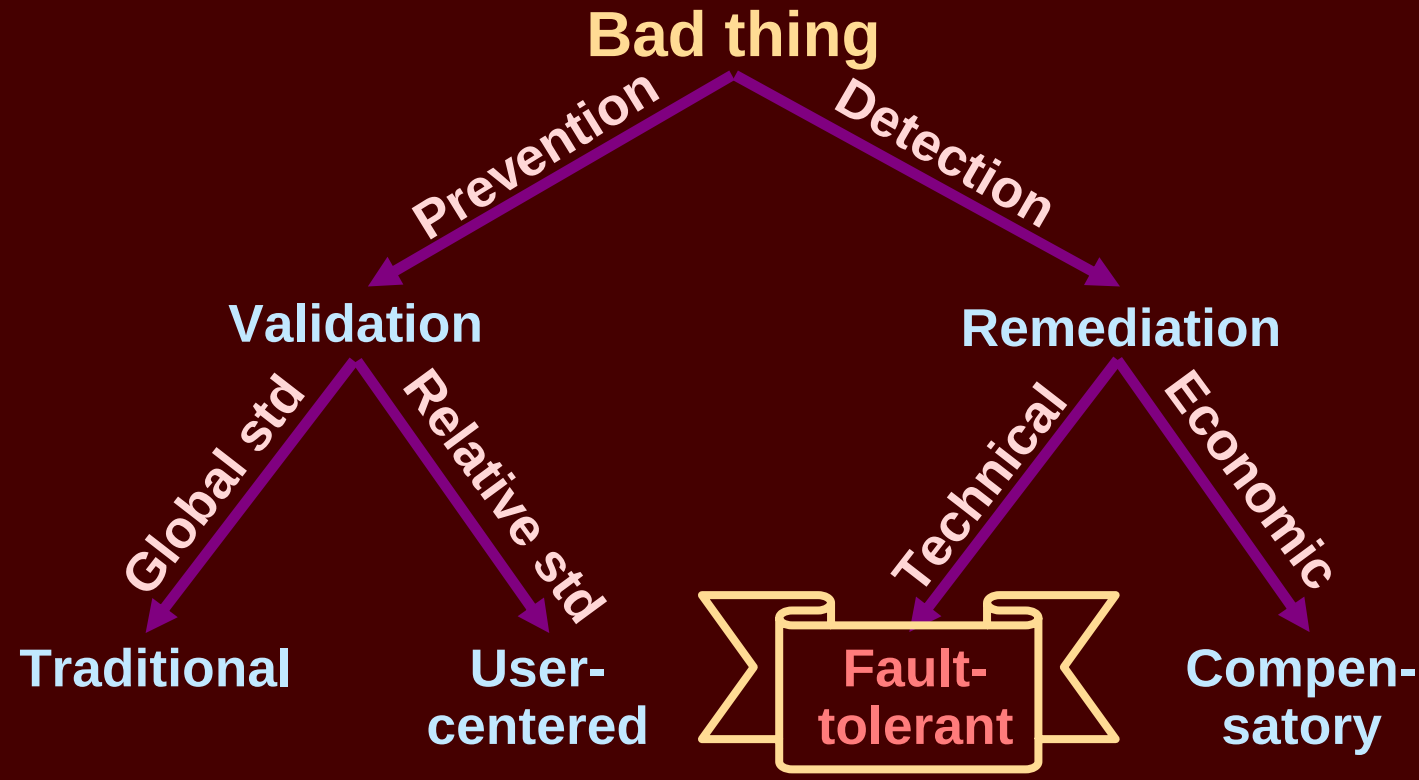
Idea: *Multidimensional cost analysis*

- Types of cost
  - Dollars, computer resources, user distraction, staff time, reputation, schedule, lives lost
- Naïve view
  - Convert all costs to a single scale, e.g., dollars
- Problem
  - Cost dimensions have different properties
- Resolution
  - Carry cost vector as far into analysis as possible
  - Convert to single scale at the latest point possible
- Butler and Poladian, independently

Idea: *Calculus of preference*

- Needed: a way to reconcile conflicting information
  - Multiple stakeholders
  - Multiple sources of credential information
  - Nonmonotonic information
- Possible contributing technologies
  - Utility theory: combining utility functions
  - Multi-attribute decision theory
  - Auctions
  - Priority scheduling
  - Engineering design judgments for reconciling conflicting constraints

Ways to deal with failure



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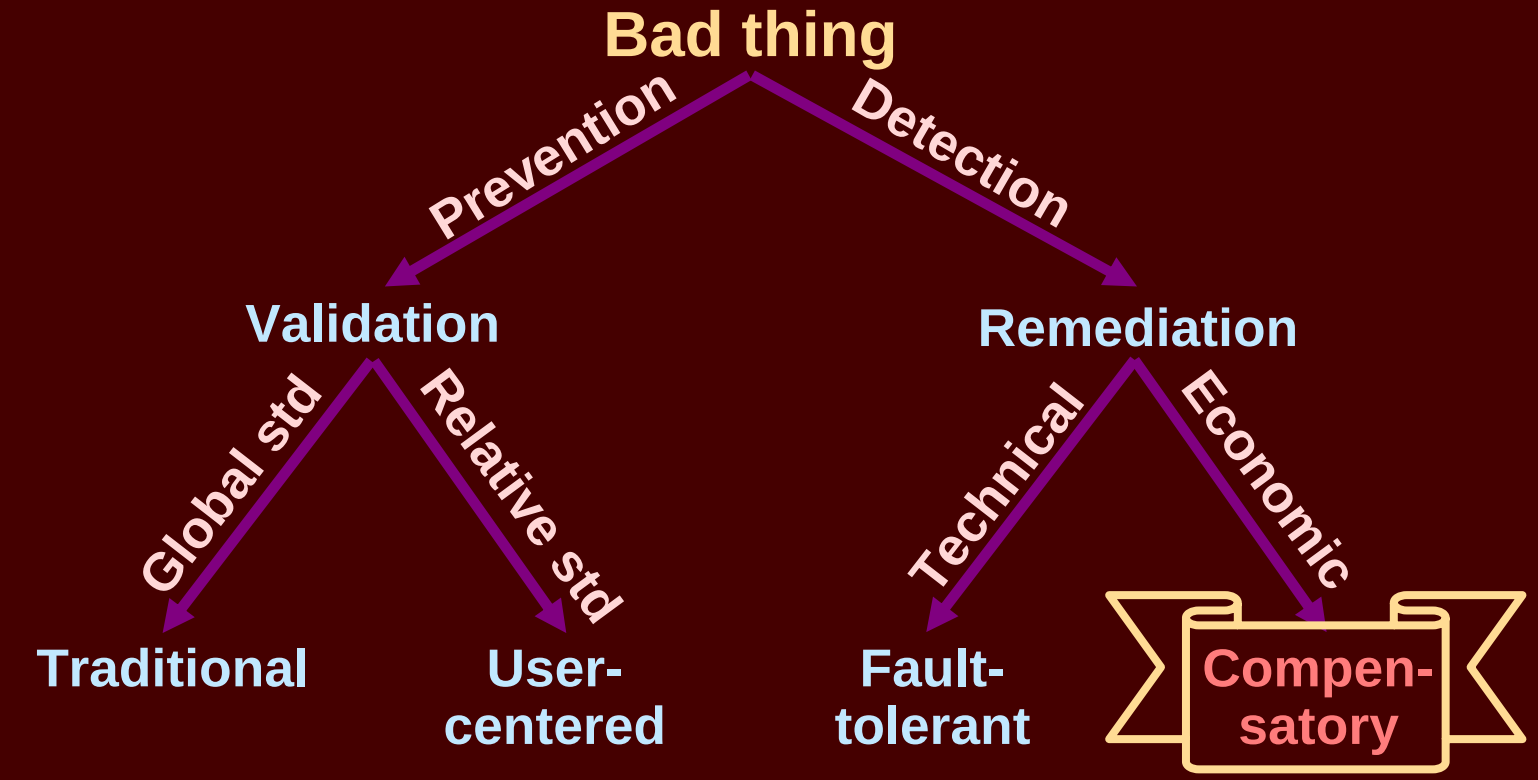
Anomaly Detection

- If you have specifications, you can detect violations
- Most everyday software does not have good specs
- Problem: how to discover "normal" behavior and capture this as predicates
  - Infer predicates from resource's history
  - Set-up elicits user expectations while tuning predicates
  - Operation applies inferred predicates
- Inferred predicates serve as proxies for specs
- Orna Raz (PhD thesis research in progress)
  - Paper in ICSE 2002

Ways to deal with failure



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Compensation, not Prevention

- For everyday software, compensation may be a reasonable alternative to repair
  - Especially for time-dependent results
  - Especially if consequences of failure are large enough to matter but not large enough to be catastrophic
- Compensation techniques need
  - Actuarial model
    - Failure rate prediction based on component history
    - Definitions of share-risk pools
  - Ways to identify failure (e.g., anomaly detection)
  - Means of assessing damages
- ***Software component insurance***
- Paul Li (2nd year PhD student)

Everyday Software

- The computing game has changed
  - ***Distributed interdependent communities of user-managed resource coalitions***
- Criteria for evaluating systems must change
  - ***User-centered requirements***
  - ***Sufficient correctness***
  - ***Value-based software engineering***
- The dependability game should also change
  - ***Portfolio selection***
  - ***Anomaly detection***
  - ***Homeostasis***
  - ***Software component insurance***

For everyday software, set criterion for dependability as “fitness for the task at hand”

Consider a wide range of approaches to achieving dependability

Achieve value through technical approaches adapted from economics and social science

Contacts

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- Students
  - Shawn Butler (security technology selection)
  - Orna Raz (semantic anomaly detection)
  - Vahe Poladian (mobile dynamic configuration)
  - Paul Li (software component insurance)
- Assistant
  - Janet New Hilf

Idea: *Aggregate Reasoning*

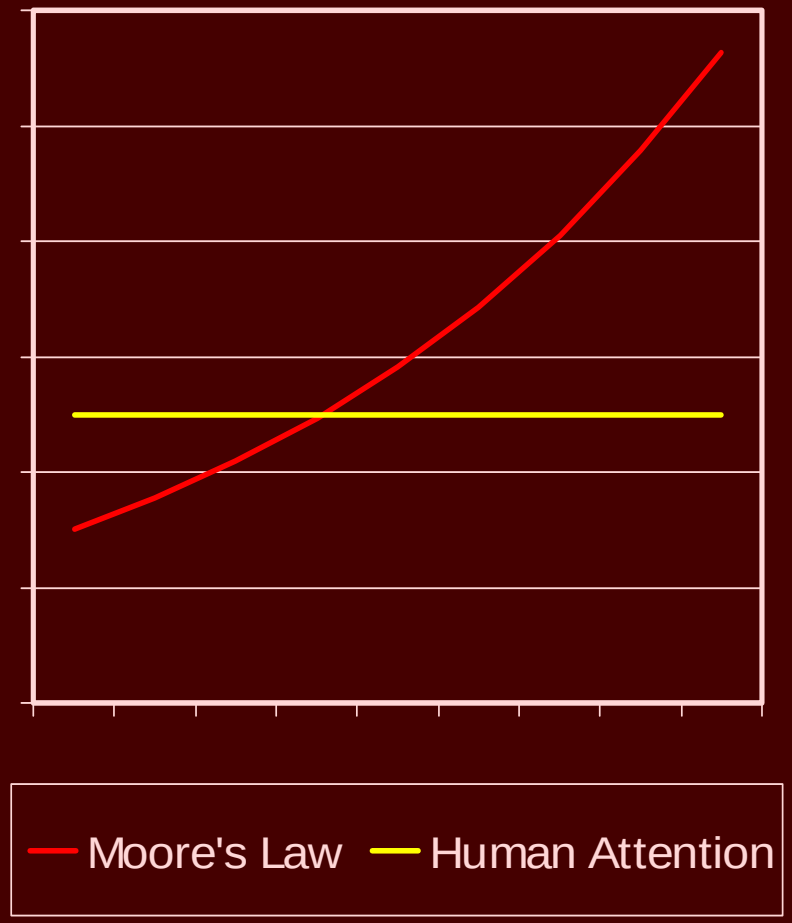
- Recognize that software systems are too complex for exact analysis
  - We don't understand gasses by solving the N-body problem for extremely large N. Instead, we use the aggregate gas laws PV = nRT
- Seek aggregate models with system-level abstractions
  - Anomaly detection, software component insurance
  - Probabilistic certification of software components provides alternative to verification (Wallnau)
  - Exact "webs of trust" would be fragile; based on preponderance of evidence they might be robust
  - Modeling Internet as "scale-free system" yields new results, e.g. about virus spread characteristics (Barabasi)

Everyday Software

- The computing game has changed
  - Internet supports mobility and a vast sea of resources
  - User expectations imply context-sensitive requirements
- Criteria for evaluating systems must change
  - Costs matter, not just capabilities
  - Specifications will inevitably be incomplete
  - “Good enough” is good enough
- The dependability game should also change
  - Reconcile conflicting objectives
  - Augment incomplete specs with user expectations
  - Use homeostasis as alternative to feedback
  - Provide compensation as alternative to repair

The Mobile Computing Challenge

- Limited hardware
  - Computer power, disk & memory capacity, battery
- Uncertain, dynamically varying services
  - Bandwidth, latency
  - Locally available information services
- Costly human attention
  - Individual, time-varying utility functions
  - Usage vs administration
  - Multi-user utility conflicts



Internet Resources as Components

Unlike conventional software components

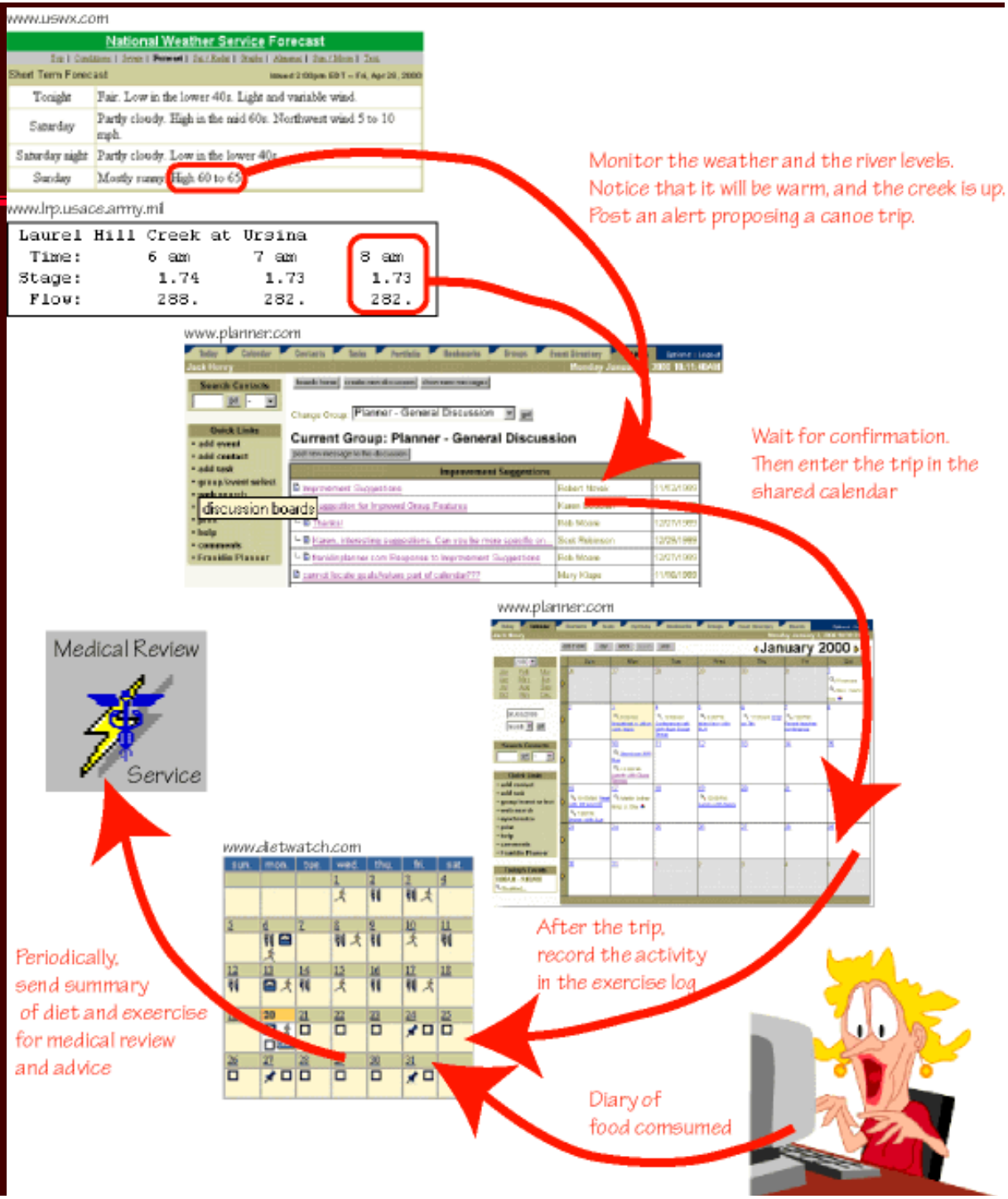
- Autonomous
  - Independently created and managed
  - May change structure or format without notice
  - Availability, format, semantics may change
- Heterogeneous
  - Different packagings
  - Different business objectives, conditions of use
- Open affordances
  - Independent systems, not dependent components
  - Output usually for viewing, not computation
  - Incidental effects may be useful

Open Resource Coalitions

Objective: compose autonomous distributed resources

- "Coalitions" because the resources will not have a shared objective
- "Open" in contrast to control assumed for closed-shop development

This changes everything!



What's changed?

Classical	*New*
Localized	***Distributed***
Independent	***Interdependent***
Installations	***Communities***
Centrally-administered	***User-managed***
Software	***Resource***
Systems	***Coalitions***

Amitabh Srivastava's Description

From his keynote talk yesterday …

- We don't know how software will be used:
  - Dynamic
  - Heterogeneous
  - Distributed
- Software evolves continually
- Development is still manual
- Increased requirements for
  - Security
  - Continuous operation
  - Maintenance
  - Change

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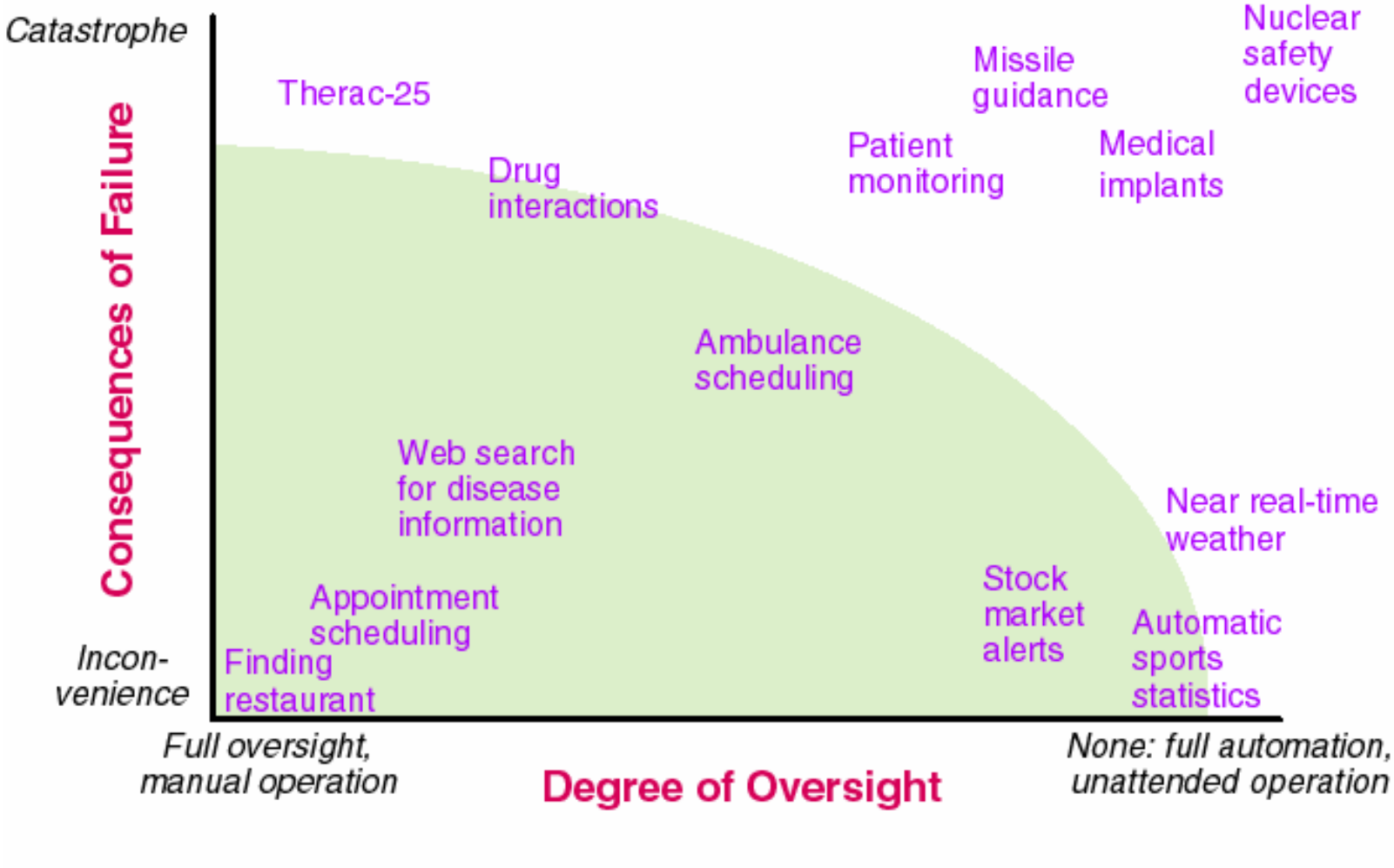
Context-Sensitive Requirements

- Different users have …
  - …different tolerance for system error and failure
  - …different interests in results from a resource
  - …different tolerance and interests at different times
- Criteria for proper operation should reflect these differences
  - Requirements can't be tied solely to resource
  - Users need ways to express differences
- Multiple co-located users must mediate preferences
- Need ***user-centered requirements*** as part of resource composition techniques

Sufficient Correctness

- Traditional model of program correctness
  - Gold standard is functional correctness
  - For systems, also need extrafunctional properties
- In practice
  - Most software in everyday use has bugs …
    - … yet we get work done
  - It isn't practical to get complete specifications
    - Too many properties people can depend on
    - Variable confidence in what we do know
    - Too expensive to collect specification information
    - Specifications should reflect users' needs
  - We don't really need "correctness", but rather assurance that the software is good enough for its intended use

Sufficient Correctness



Programs vs Systems

Programs	Systems
Complete knowledge	Approximate knowledge
Goal: correctness	Goal: adequacy, fitness
Failure prevention	Problem remediation
Good component specs	Components poorly understood
Monolithic design	Cohesion / coupling issues
Stable configuration	Shifting (dynamic) parts
Open loop operation	Closed loop operation
Requirements tied to components	Requirements sensitive to context of use
Greenfield	Brownfield
Cost not a major factor	Cost a design driver
Creating capability	***Creating value***

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The Value Proposition

- *Engineering seeks timely, cost-effective solutions to practical problems, preferably based on math and science*
  - This entails reconciling conflicting constraints.
  - This entails making decisions with limited time, knowledge, and resources
  - This entails understanding the contribution of design decisions to cost as well as to capability

. . . and so . . .

- The objective of software engineering should be to ***create value***, not simply to create capability

Value-based Software Engineering

- Include cost-benefit tradeoffs in technical decisions
  - cost-benefit of getting information as well as of analysis
  - cost-benefit of ownership as well as of development
- Adapt techniques such as

machine learning	multi-attribute decision theory
utility theory	linear programming
real options	classical optimization
game theory	portfolio selection

  from business, economics, social sciences
- *Harnessing the knowledge of other disciplines, especially social scientist, in service of better software*

Everyday Software

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- Criteria for evaluating systems must change
  - ***User-centered requirements***
  - ***Sufficient correctness***
  - ***Value creation, not just capability creation***
- The dependability game should also change
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Types of self-healing

- Distinguish external from internal environment
  - System has control over internal environment
  - External environment operates independently
- Fault-tolerance through feedback
  - Internal: detect system state, compare to criterion, repair if necessary, good knowledge for planning
    - Load balancing, adaptive integration
  - External: attempt to infer external state, compare to objective, react if necessary,
    - Control of mechanical systems
- Homeostasis
  - Design so normal operation maintains good conditions
    - Internet packet routing, background garbage collection