Course "Empirical Evaluation in Informatics"

Other methods

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- Simulation
  - example: P2P scalability
- Legacy data analysis
  - example: code decay
- Literature study
  - example: model for review effectiveness

"Empirische Bewertung in der Informatik"

Sonstige Methoden

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- Simulation
  - Bsp: P2P-Skalierung
- Analyse vorhandener Daten
  - Bsp: Code-Verfall
- Literaturstudie
  - Bsp: Modell f. Effektivität von Durchsichten

The methods landscape

- Again, we look at
  M. Zelkowitz and D. Wallace:
  "*Experimental Models for Validating Technology*",
  IEEE Computer 31(5), May 1998.

- Considers three broad categories of validation methods:
  - **Observational:**
    Observe a process as it unfolds, but influence it hardly or not at all
    - Case Study
  - **Historical:**
    Observe evidence of a process after the fact
    - Survey, Legacy Data Analysis, Literature Study
  - **Controlled:**
    Observe a process, with purposeful influence on the process characteristics
    - Controlled Experiment, Quasi-Experiment, Benchmarking, Simulation

Simulation

- Approach:
  - Formulate a model of some process or system
  - Implement that model as a program
  - Set parameters and run the model; vary parameters
  - Observe behavioral variables of interest

- Advantages:
  - Can produce lots of data for fairly complex situations at low cost
  - Allows to study *emergent properties* that are beyond analytical understanding and to describe the conditions under which they emerge

- Disadvantages:
  - It is very difficult to validate that the model is appropriate/right/valid with respect to the variables of interest

Simulation: Application areas

- Study systems that do not (yet) exist or are hard to observe
  - e.g. proposed hardware architectures
  - e.g. networks of 10000 new mobile devices
  - e.g. the whole Internet
- Study systems that evolve only slowly
  - e.g. software process simulation for project planning
    - (this is how the weather forecast is computed)
- Study effects of impossible or impractical manipulations
  - e.g. disaster studies of the Internet infrastructure
  - e.g. studying certain traffic situations for a class of potential future networks
  - e.g. what-if studies of software project dynamics

Simulation example: Scaling a P2P network

- Yatin Chawathe, Sylvia Ratnasamy, Lee Breslau, Nick Lanham, Scott Shenker: "*Making Gnutella-like P2P systems scalable*", Proc. ACM SIGCOMM 2003

- Proposes a system called GIA that improves scaling behavior
  - http://www.planet-lab.org/

Chawathe

Ratnasamy

Breslau

Shenker

Peer-to-peer networks

- Standard client/server networks have disadvantages:
  - Restricted scalability: Server overload in high-traffic situations
  - Limited availability: Single point of failure
  - Servers are expensive and require much maintenance and administration effort

- Peer-to-peer (P2P) networks try to avoid this:
  - Each node is client and server at once
  - Network is totally de-centralized:
    Structure, reliability, administration
  - P2P networks are typically overlay networks:
    a logical network layered on top of an existing network
    - (The Internet is also an overlay network)

P2P applications

- P2P networks have many applications
  - end-user file sharing (e.g. Gnutella)
  - ad-hoc networks of mobile devices
  - distributed databases
  - electronic currency (e.g. Bitcoin)
  - etc.

- We only look at file sharing here

P2P approaches

- Solution 1: Flooding (e.g. Gnutella)
  - Performs searches by recursively asking all neighbors in the network
    - Up to a maximum distance of hops (time-to-live parameter)
  - Requires O(n) steps with n nodes to find a file
  - Potentially bad scaling behavior: at high load, the network quickly becomes globally overloaded

- Solution 2: Distributed Hash Tables (DHTs)
  - De-centralized solution for mapping a filename to a host
  - Can locate the node holding a file in O(log n) steps for n nodes
  - Potentially much better scaling behavior
  - However, keyword searching is not directly supported

P2P file sharing phenomena

Mass file sharing is a rather specific P2P problem:

1. Extremely transient node participation
    - e.g. average uptime of 60 minutes in Gnutella
   - No problem for flooding; expensive for maintaining DHTs
2. Very heterogeneous node capacity (connection bandwith)
3. Many more keyword searches than full-filename queries
   - Because exact file names are rarely known
   - This is no problem for flooding, but requires complex additional mechanisms to be accomodated by DHTs
4. Most queries are for highly replicated files
   - What is in popular demand is also offered frequently
   - This means flooding can actually be much cheaper on average than expected
     - and DHTs biggest strength is not so important at all

Improving flooding: GIA

- Replace flooding by random walk
  - e.g. consider only 1 random neighbor instead of all
- Problems:
  - Random walk is blind: does not consider that some neighbors might be more promising than others
  - If it hits an overloaded node, it will be stalled
- GIA improvement suggestions:
  - **TADAPT**: Give high-capacity nodes more neighbors
    - So that those nodes receive most queries that are best up to handle them
  - **BIAS**: Bias the random walk towards high-capacity nodes
  - **FLWCTL**: Active flow control to avoid overloaded nodes
  - **OHR**: Replication of file name lists to one-hop neighbors
    - so that high-capacity nodes can answer very many queries

Protocol variants considered

The study now investigates four variants of Gnutella-style file sharing protocols:

- FLOOD:
  - The standard Gnutella protocol
- RWRT:
  - Random walks over random topologies
- SUPER:
  - Discriminate supernodes and non-supernodes.
    Do flooding only over the supernodes
    - Not discussed here
- GIA:
  - All four improvements as described before

- Now set up a simulation

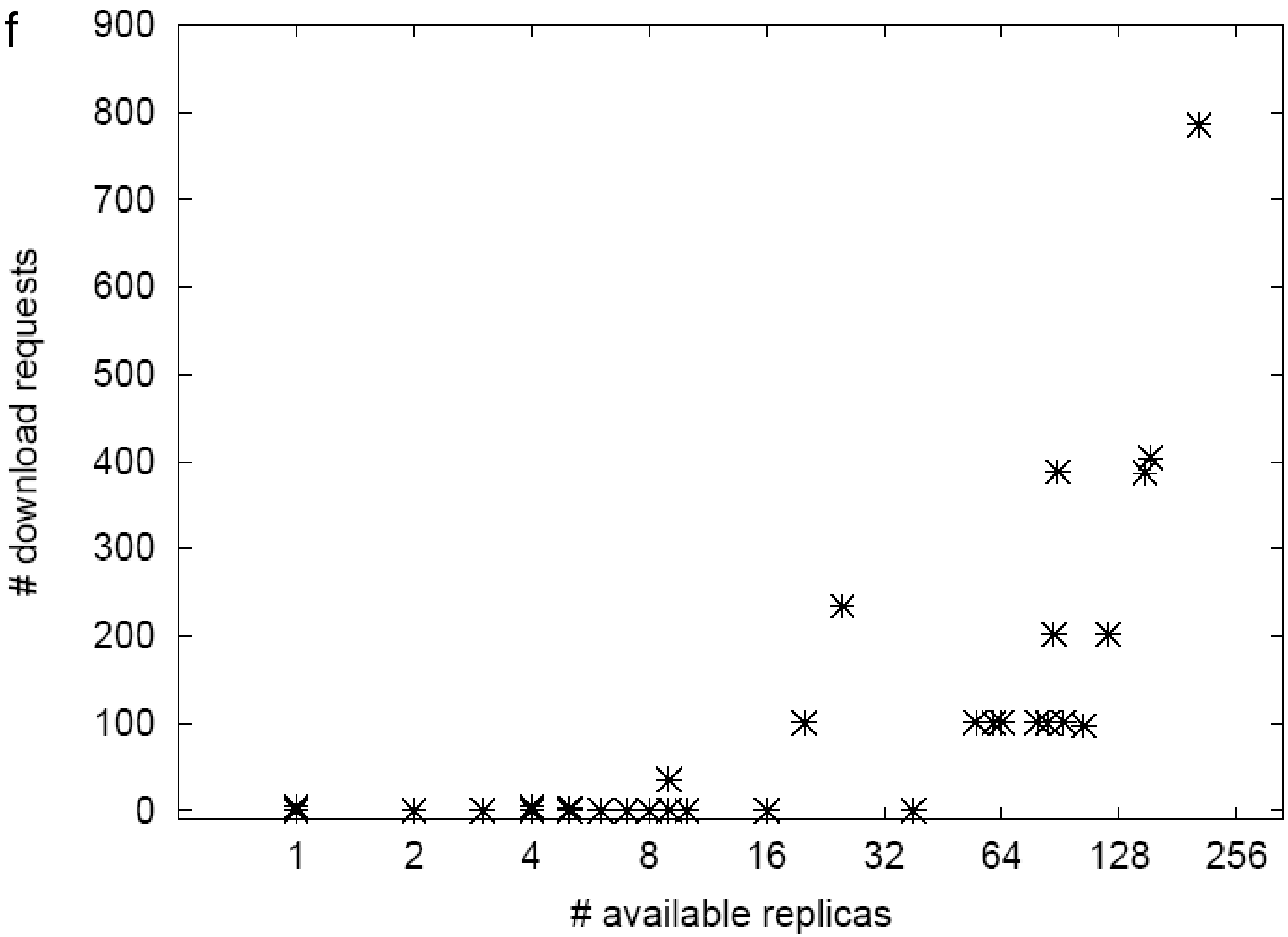
Setting simulation parameters

Capacity level	Percentage of nodes
1x	20%
10x	45%
100x	30%
1000x	4.9%
10000x	0.1%

- Take distribution of node capacity from another study
  - and simplify it to make it practical
- Assign the 1000x and 10000x levels to be the supernodes (high-capacity nodes)
  - Not discussed here
- Assume constant query-generation rates for each node
  - bounded by node capacity
- Topology: Set number of neighbors in range 3...128
  - average degree is 8
  - limit neighbors for low-capacity nodes
  - average resulting network diameter is 7
- Time-to-live:
  - 10 for FLOOD/SUPER,
  - 1024 for RWRT/GIA

Setting simulation parameters (2)

- Consider different (fixed) "replication factors": The fraction of nodes that can fulfill a given query
  - derived from separate mini-study of actual Gnutella replication and query behavior



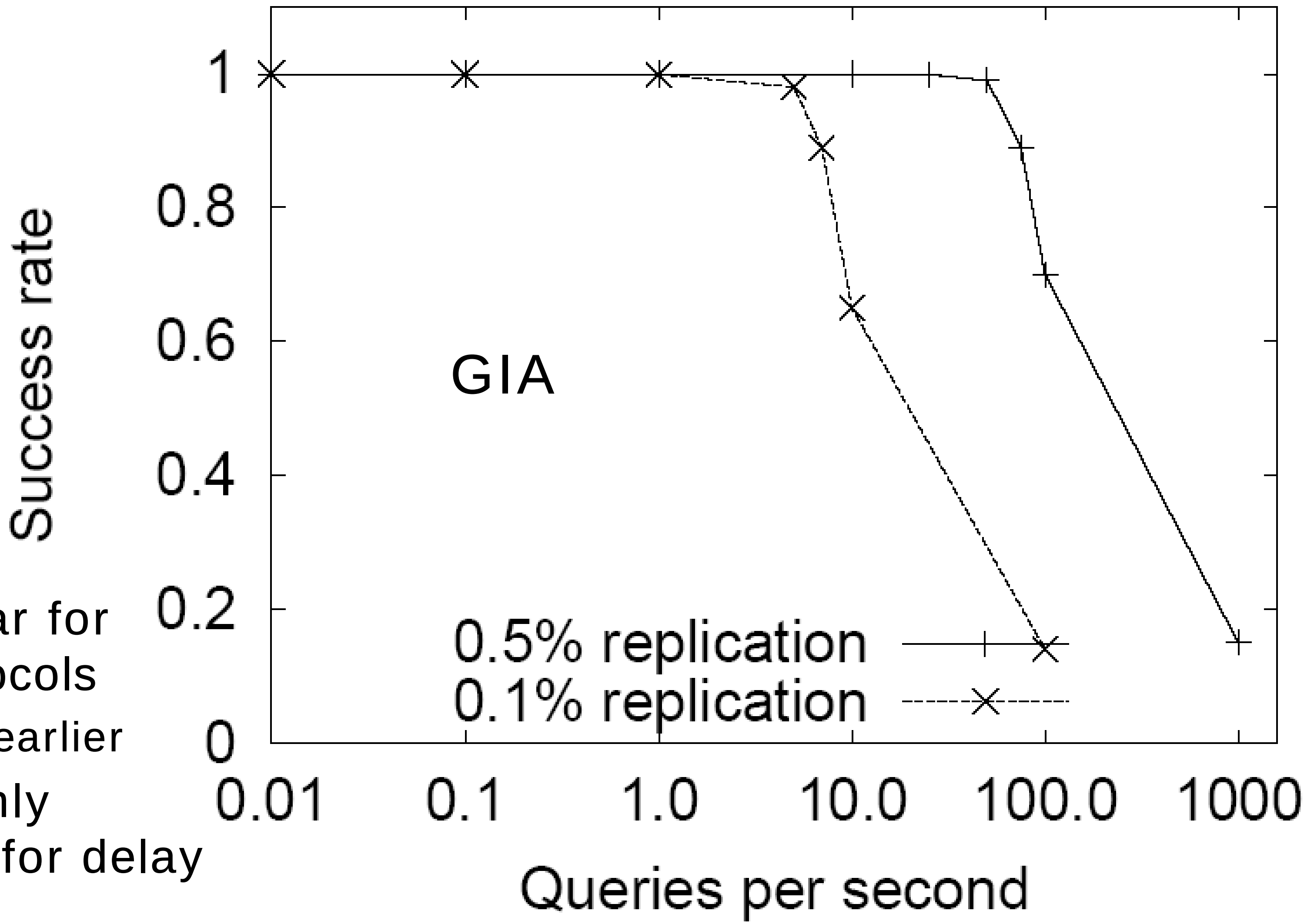
Performance measures

The simulation considers three measures of goodness:

- success rate:
  - Fraction of queries that locate the file (which always exists)
- hop count:
  - Number of communication steps required for a query
- delay:
  - Time until a query returns its result

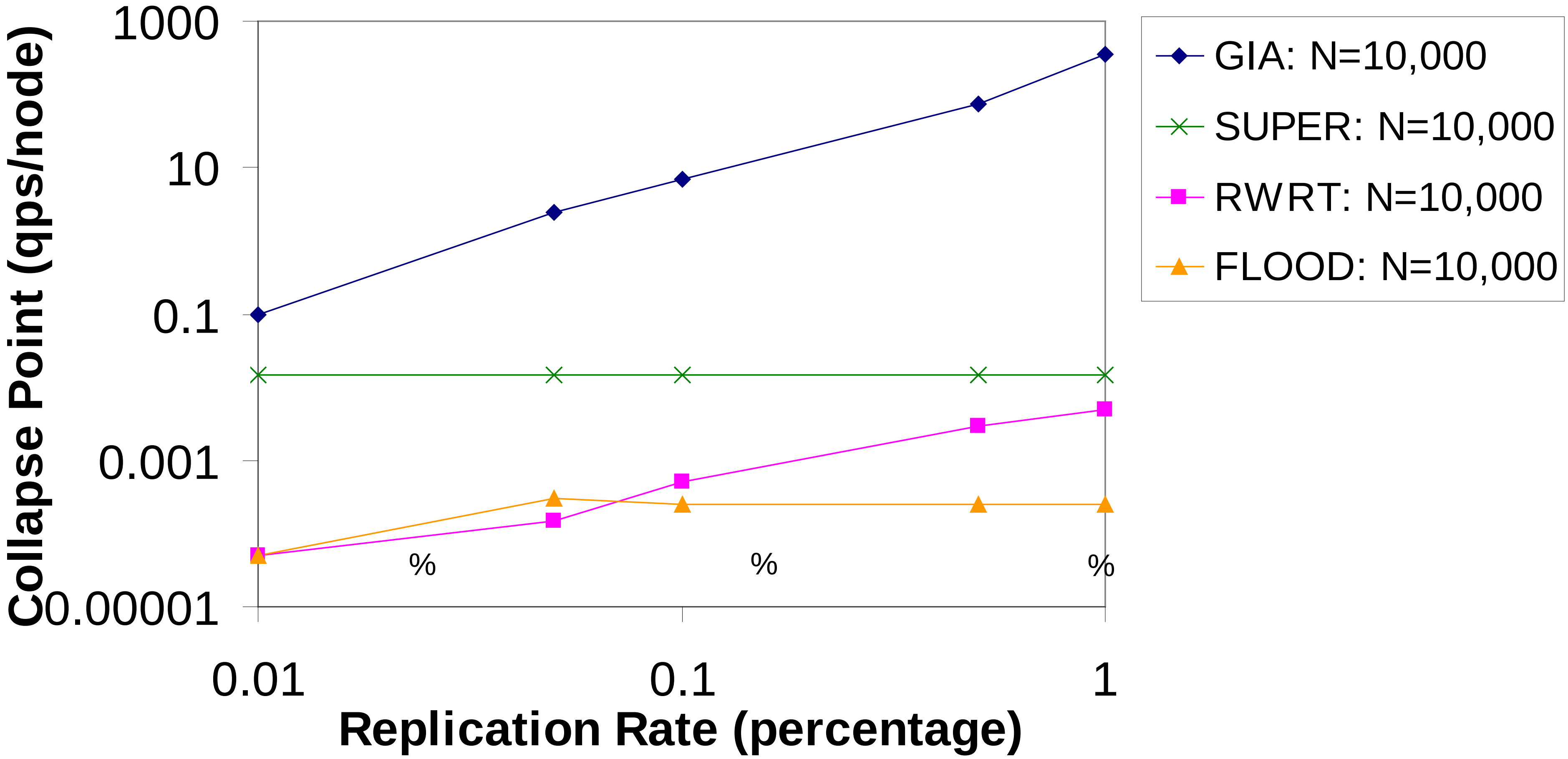
- query load = 0.1 means that in each time unit, each node issues 0.1 queries (0.1 qps/node)

Simulation results: Collapse point effect



- Is similar for all protocols
  - only earlier
- Is roughly inverse for delay

Simulation results: Collapse point comparison



Factor Analysis

Algorithm	Collapse point
RWRT	0.0005
RWRT+OHR	0.005
RWRT+BIAS	0.0015
RWRT+TADAPT	0.001
RWRT+FLWCTL	0.0006

Algorithm	Collapse point
GIA	7
GIA – OHR	0.004
GIA – BIAS	6
GIA – TADAPT	0.2
GIA – FLWCTL	2

No single component is sufficient alone;
only the combination of all of them makes GIA scalable

Summary of simulation example

- Topic:
  - A P2P file sharing system with severe scalability problems
  - Now exploit known specific characteristics,
    - in particular heterogeneity of node capacity
  - to propose four improvements

- Evaluation approach:
  - Evaluate relative performance of the improvements in large-scale use by means of simulation
  - Obtain important simulation parameters by instrumental mini-studies
    - **Using the right parameters is crucial!**

- Overall: **Fairly complicated!**

Topics today

- Simulation
- **Analysis of legacy data**
- Literature study

Analysis of legacy data

- Approach:
  - Analyze existing sets of data
    - initially called "software archaeology",
      now called "mining software repositories"
    - very many different approaches are possible
  - Investigate new questions or look at more data at once

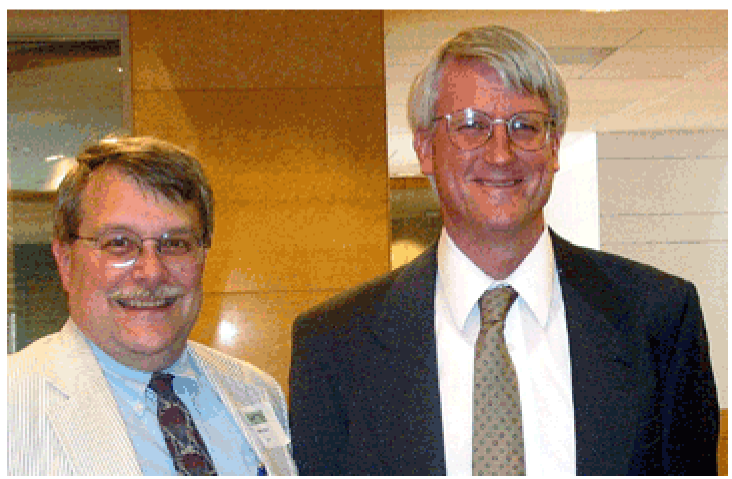
- Advantages:
  - Can sometimes use large amounts of data with low effort
  - Questions only found later can often be answered just as well as the original ones

- Disadvantages:
  - If additional data is required, it may be impossible to get it
  - Data quality can be hard to assess

Analysis of legacy data example

- Stephen G. Eick, Todd L. Graves, Alan F. Karr, J. S. Marron, Audris Mockus: "*Does code decay? Assessing the evidence from change management data*",
  IEEE Trans. on Software Engineering 27(1):1-12,
  January 2001.

Graves　　Karr　　Marron　　Mockus



Study question

- Do the common software engineering practices lead to code decay when a large software system is frequently changed over a long time?

- A unit of code is considered *decayed* if it is harder to change than it could be (e.g. harder than it used to be)
  - measured in terms of effort, interval and quality

Possible reasons for code decay

- Inappropriate architecture
  - Code cannot accomodate a change well
- Violation of design ideas
  - One change done in an inappropropate way makes further changes difficult
- Inadequate change environment
  - e.g. maintenance tools, organizational environment, change processes
- Programmer variability

All these are exacerbated by:

- Time pressure
- Imprecise requirements
  - Producing a sequence of changes rather than just one

Software system studied

The software of a telephone switching system

- About 100 Mio. lines of C code total
  - plus 100 Mio. lines of other files (header files, make files)
  - 50 major subsystems, 5000 directories
  - Each release consists of about 20 Mio. lines of code
- Under development since 15 years
  - About 10000 developers have worked on it

The data studied

- The full change history of the code of one subsystem
  - as recorded in the version management system
  - 100 directories, 2500 files
- Changes are described on four levels of increasing granularity
  - delta: a change to one file from one revision to the next
  - modification request (MR): description of a solution to a problem
  - initial modification request (IMR): description of a problem to be solved
  - feature: a marketable function of the system as a whole
- Change history is available for files, MRs, IMRs, features
  - 130 000 deltas, 27 000 MRs, 6 000 IMRs
  - 500 people making changes

Plausible symptoms of decay

- Excessively complex ("bloated") code
- A history of frequent changes ("code churn")
- A history of faults
- Widely dispersed modifications within one change
- Kludges
- Numerous interfaces (e.g. many entry points)

- The study defines CDIs (code decay indices) for some of these symptoms
  - The indices are based directly on the version management data

churning

Risk factors for decay

A code unit has a higher probability of decaying
if the following factors are high:

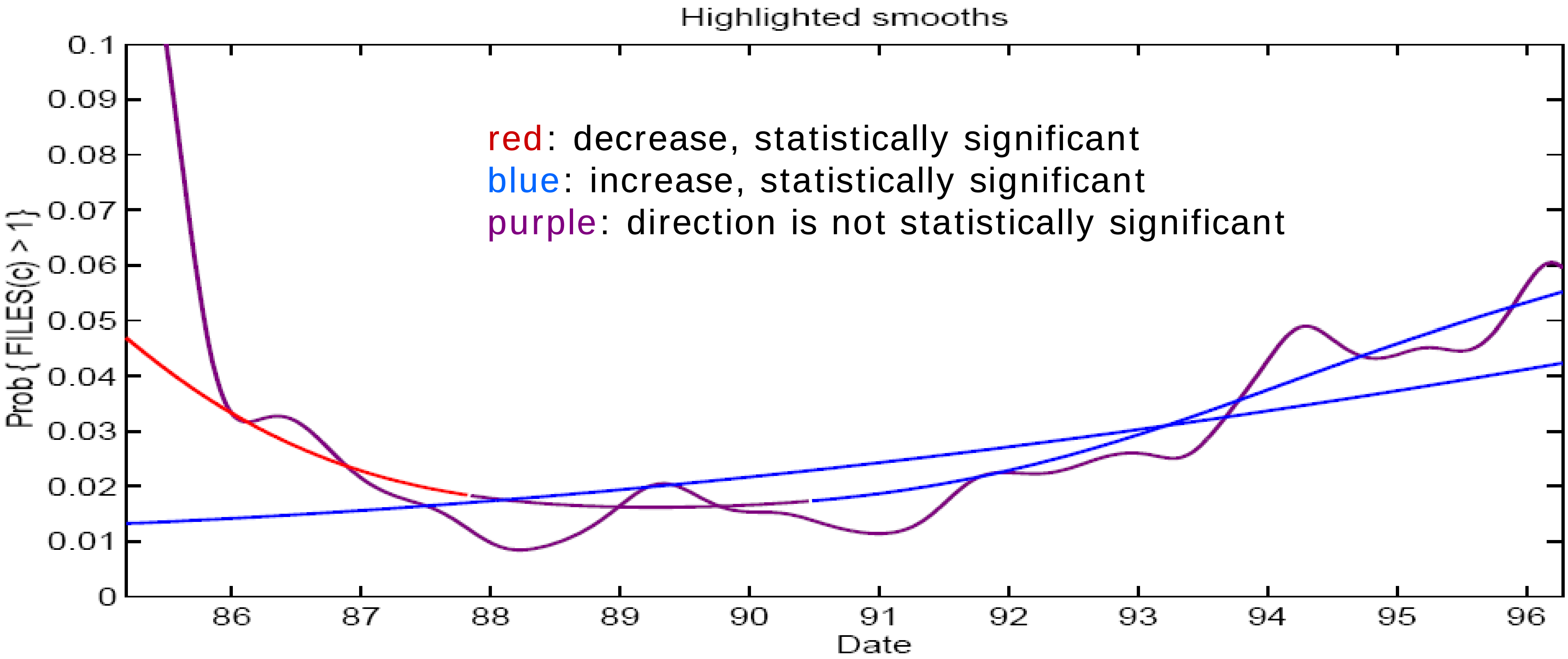
- Size
  - large units tend to decay more easily
- Age
  - although very stable code can be rather old without decay
- Inherent complexity, e.g. due to requirements load
  - code that must do many things or difficult things
- Organizational churn or inexperienced developers
  - makes design violations more likely
- Porting or reuse

- Like before, CDIs are defined for some of these

Results

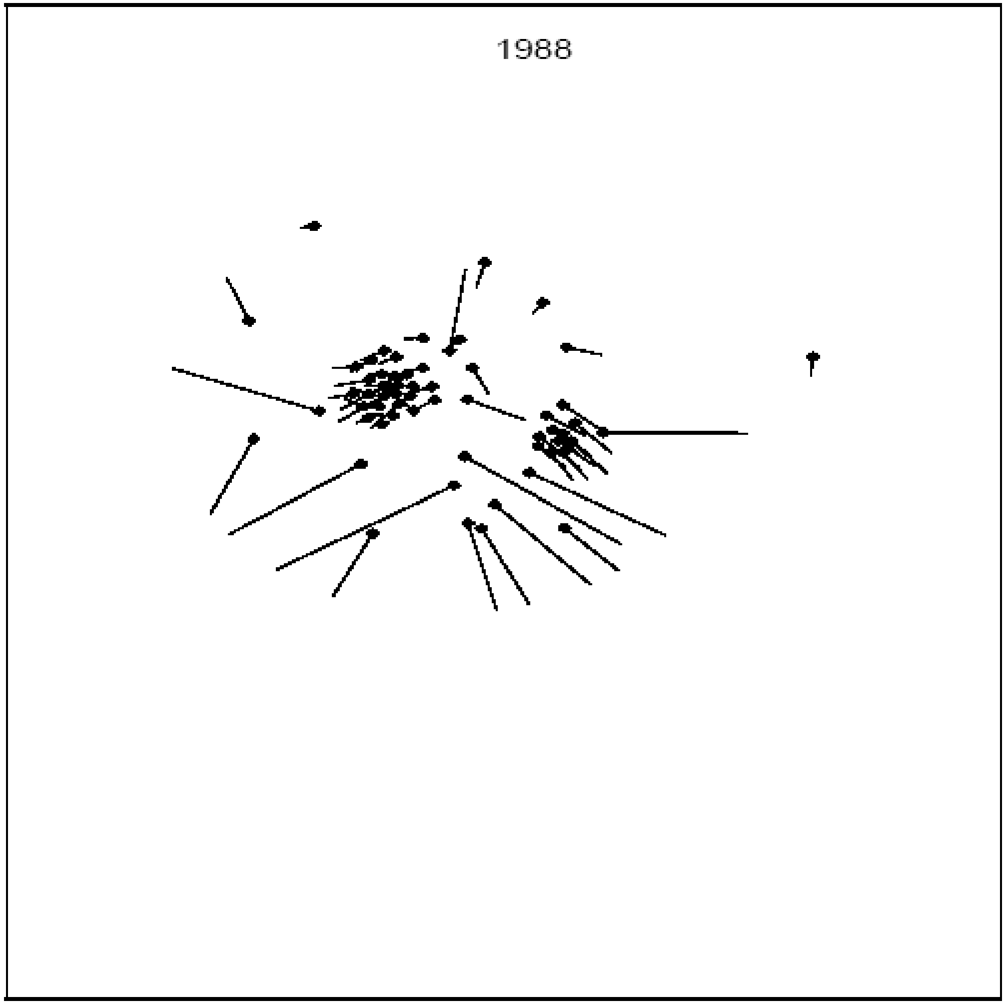
There is code decay in this system, as indicated by:

- The span of changes increases over time
  - loess smooths w. span 0.3 (purple), 1.5 (r/p/b), 7.5 (blue)



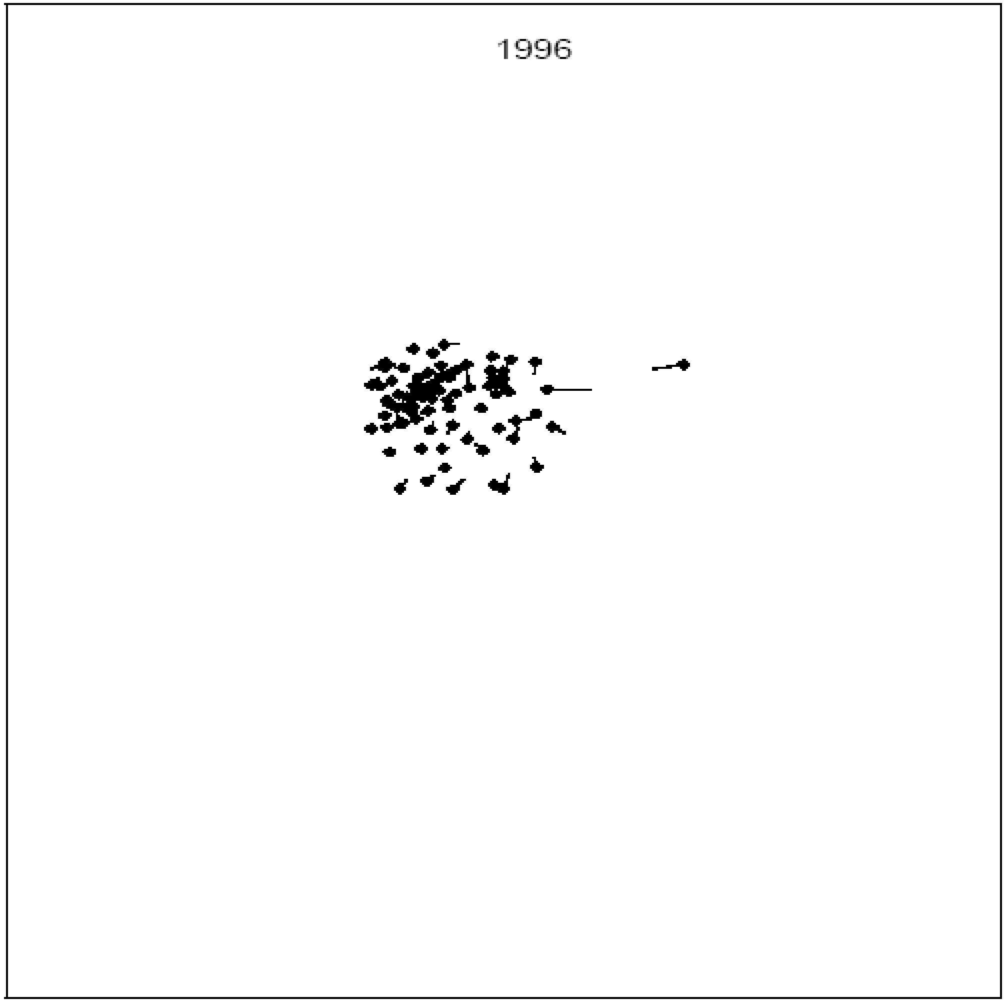
Results (2)

- The increase in span is accompanied by a breakdown of modularity in the code
  - each point (pin head) represents one directory
  - positions are such that dirs often changed together are close together
  - the tail indicates the position one year before
  - there are two clear clusters
    - and then some



Results (3)

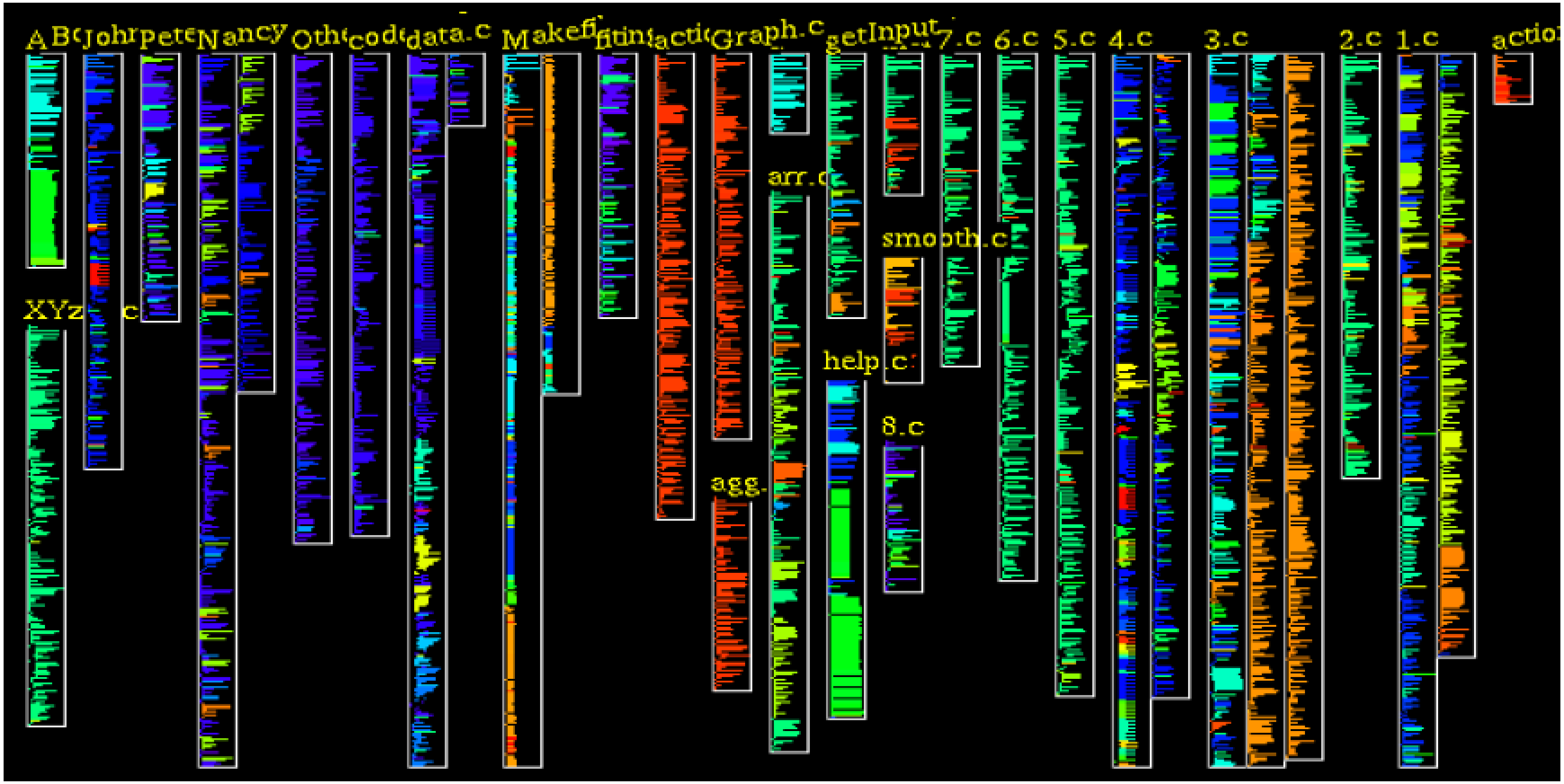
- 8 years later, the large-scale modularity has almost completely disappeared



(a very good visualization!)

A side note: SeeSoft

- A tool for visualizing aspects of source code lines
  - rectangle: file, line: line, color: age of line
    - many other visualizations are available as well



Summary of legacy data example

- Analyzing legacy data allows for evaluating large-scale situations
  - extending over a long time
  - representing an immense number of events

- If done carefully, such analyses can be very credible
  - although we have not discussed the details of the arguments used here
  - External validity may be difficult to obtain, though

Topics today

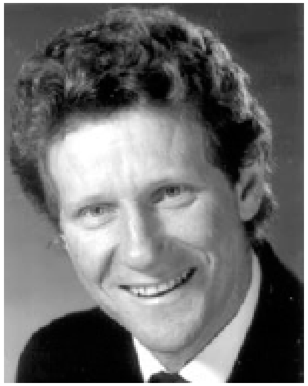
- Simulation
- Analysis of legacy data
- **Literature study**

Literature study

- Approach:
  - Review multiple published empirical studies on a similar topic
  - Draw conclusions based on the union of the data or results
    - Conclusions that are not possible from any one study alone
    - If this follows a rigorous protocol, such studies are now called **Systematic Literature Reviews (SLRs)**
- Advantages:
  - Relatively low effort
  - Can in principle provide a very broad empirical basis
- Disadvantages:
  - There are rarely enough similar studies on one topic
  - "file drawer problem": Unsuccessful studies remain published
    - Hence the unified picture from a literature search may be biased
  - Publications often lack important detail information

Example for Literature Study

- C. Sauer, D.R. Jeffery, L. Land, Ph. Yetton:
  "*The Effectiveness of Software Development Technical Reviews: A Behaviorally Motivated Program of Research*"
  IEEE Transactions on Software Engineering 26(1): 1-14, January 2000.

Definition
"Software Dev. Technical Review"

- Software Development Technical Reviews (SDTRs) are
  - an organizational device
  - for detecting defects in software products
  - at any stage of the life cycle
  - and for obtaining secondary benefits
  - through a two-stage process
  - in which software engineers first independently inspect the software product for defects and then
  - combine their efforts in a group meeting
  - in which the participants adopt roles
  - with the goal of producing a report
  - in which all the defects agreed upon by the group are identified.

- This includes inspections, reviews, walkthroughs, etc.

Goals of the study

- Long-term goal
  - Obtain a validated theory explaining the effectiveness of SDTRs in terms of a number of influencing factors

- Goal of the current work
  - Formulate a set of propositions that outline such a theory
  - Some of these propositions may be entirely unvalidated
  - Most are only partially validated
  - Therefore, the propositions describe a research program
    - Thus the title of the article

Approach of the study

Approach:

- Take an existing theory of group behavior for a class of two-stage decision tasks
  - developed by research on social psychology

- Apply this theory to SDTRs and formulate according propositions

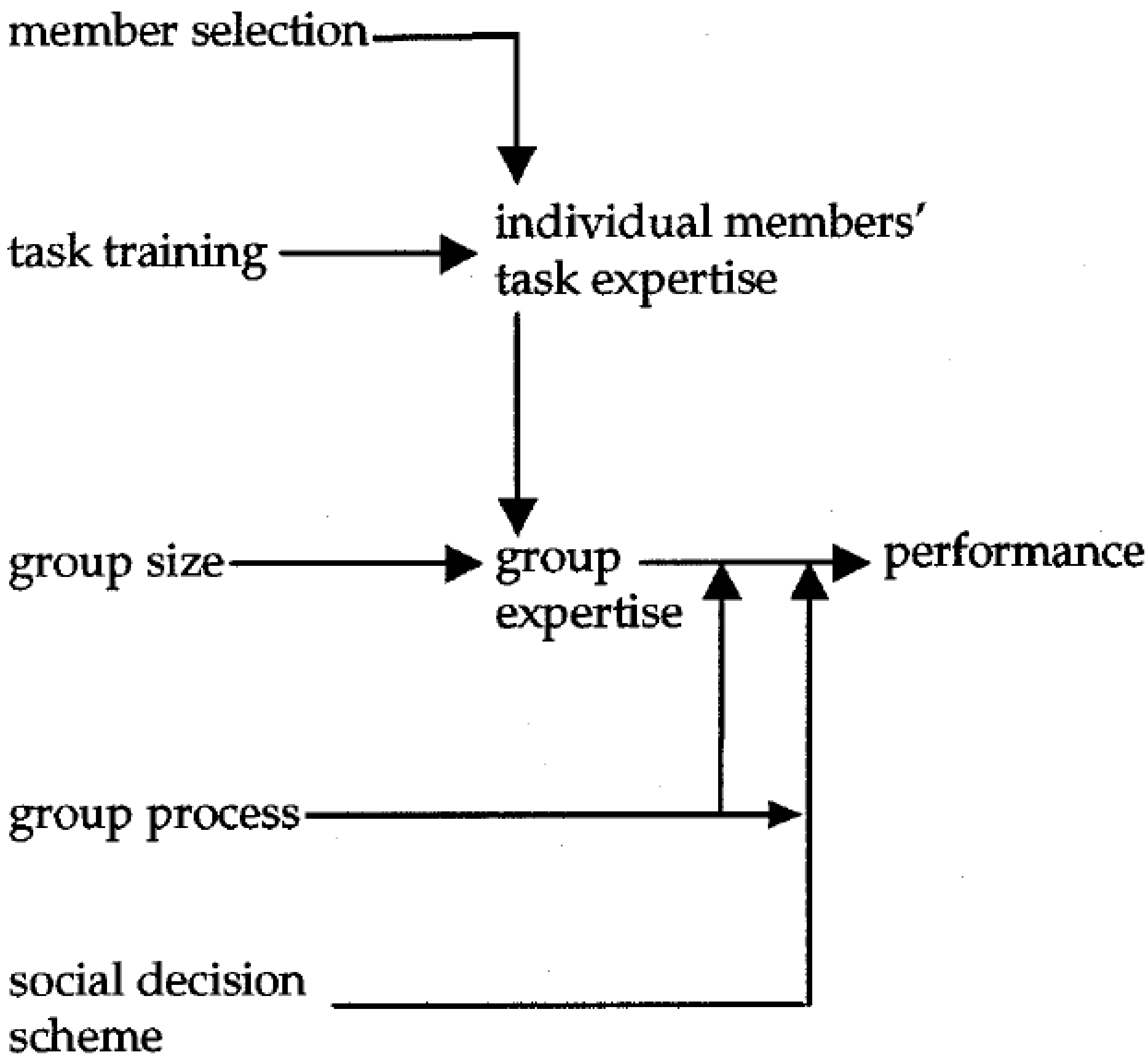
- Review all previous studies on technical reviews to find support for the propositions -- or lack thereof
  - The article has 88 literature references

The existing theory: Tasks studied

- Group research has investigated empirically a class of problems like the following ("*Lost in the desert*"):
  - Members of a group are told to imagine they were stranded in the desert with a limited number of implements available to them, e.g., knife, string, mirror, etc.
  - Each member individually is to rank these items according to their survival value
  - Then the group meets and decides on a common ranking
- A lot of experiments have been performed and a theory of decision performance has been formulated
  - The theory can explain much of the variance observed
- The decision task resembles software inspections:
  - First individuals make up their mind
  - Then a group makes a collective decision
  - Difference: The set of defects is more open than the usefulness ranking

The existing theory: Graphical sketch

- Terms are factors
- Arrows indicate influence



The existing theory: Verbal description

- Performance is determined by effective group expertise
- If the group has a bad social decision process or other process flaws, its effective expertise will be below the available expertise
  - The decision process needs to select the best task expertise embedded in all of the members' individual rankings
- Available group expertise is roughly the union of the members' expertise
  - Thus, it tends to increase with group size
  - and it increases with the amount of members' individual expertise
  - and the dis-similarity of these
- Individual expertise depends on the amount of task training an individual has had

Propositions and evidence for them

- Applying the existing theory to SDTRs
  leads to 11 propositions
    - (We will discuss only <u>some</u> of them)
  - For some of these there is existing empirical evidence
  - For others, there is little or none

- <u>P1</u>: In SDTRs, task expertise is the dominant determinant of group performance
  - Two studies find such an effect
  - A few studies explicitly factor the influence out
  - Most studies ignore the issue

Propositions
and evidence for them (2)

- P2: In SDTRs, decision schemes (plurality effects) influence interacting group performance
  - Decision is difficult if a defect candidate has been found by only one reviewer (i.e., there is no "plurality")
  - The frequency of this is unknown, but appears to be high

- P3: In SDTRs, in the absence of a plurality, interacting group performance is a positive function of process skills
  - Having different roles in the group improves performance
  - No other evidence is available

- P4: In SDTRs, the interacting group meeting does not improve group performance over the nominal group by discovering new defects
  - Evidence (but not strong) from various studies is available

Propositions and evidence for them (3)

- P5: In SDTRs, group performance is a positive function of task training
  - The only available study reports a 90 percent user defect reduction after training in software reading techniques
- P6: In SDTRs, the performance/size relationship is a function of task expertise.
  - No evidence is available
- P7: In SDTRs, above a critical limit, performance *declines* with increasing group size
  - There is evidence for process loss from a number of studies
  - But there is no direct support for the proposition

Propositions and evidence for them (4)

- P8: In SDTRs, the performance advantage of an interacting group over a nominal group is a function of the level of false positives discovered by individuals
  - There is evidence that meetings do discriminate false positives from true defects
  - But no formal test of the proposition has been performed

- P9: In SDTRs, an expert pair performs the discrimination task as well as any larger group
  - One study reports that groups of 4 were not significantly better than groups of 2
  - But no formal test of the proposition has been performed

Propositions and evidence for them (5)

- P10: In SDTRs, nominal groups outperform alternatives (1 reviewer, best reviewer from group, review meeting) at the discovery task
  - Several studies confirm this
  - BTW: Similar results exist for brainstorming
    - Prepared individuals result in more overall ideas compared to only a brainstorming meeting
- P11: In SDTRs, the defect discovery performance/size relationship for nominal groups is a function of task expertise
  - Like P7, this has not yet been studied much

Conclusions: Consequences for research

- Several propositions need to be validated
  - This is a research program that can now more clearly be understood than before
- Reading technology research should continue
  - Roles, checklists, scenarios, perspectives, ...
  - It can make individual reviewers more effective and can improve the efficiency of larger group sizes
- We need research for understanding review expertise
  - So that we can develop proper reviewer trainings
  - Because reviewer task expertise is the single most important factor for review effectiveness

Conclusions: Consequences for practice

- For defect detection, one may be able to substitute expertise by larger numbers of reviewers
- However, too-large groups may produce insufficient motivation in the reviewers
  - One may try incentive systems to overcome this
- Defect discrimination meetings should be abandoned
  - unless false positives are frequent or harmful
- or be replaced by a single expert review-reviewer

Summary of literature study example

- Re-using what is available in the literature can be a **cost-efficient** way of obtaining empirical information
  - Note there are specific, well-defined methods for doing this: systematic literature review (SLR), mapping study, meta-analysis, thematic synthesis, etc.
- In particular, by considering more and diverse work, we may be able to **obtain more understanding** than any single study ever could
- A unified view of multiple studies can sometimes **resolve credibility or relevance problems**
- In the current state of software engineering research, **theory-building** should probably start by means of literature studies

Summary: Other methods

- There are more approaches for empirical evaluation than those we have covered in a full two-hour lecture
- Examples are
  - Simulation,
    - Example: P2P query scaling behavior (GIA) study
  - Analysis of legacy data, and
    - Example: code decay study
  - Literature studies
    - Example: theory of review effectiveness study
- Each has its specific strengths

Thank you!