Dependability Assessment of Software-based Systems: State of the Art

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Do you remember 10^{-9} and all that?

- Twenty years ago: much controversy about need for 10^{-9} probability of failure per hour for flight control software
  - could you achieve it? could you measure it?
  - have things changed since then?

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Issues I want to address in this talk

- **Why is dependability assessment still an important problem? (why haven't we cracked it by now?)**
- **What is the present position? (what *can* we do now?)**
- **Where do we go from here?**

Why do we need to *assess* reliability?

Because *all software needs to be sufficiently reliable*

- **This is obvious for some applications - e.g. safety-critical ones where failures can result in loss of life**
- **But it's also true for more 'ordinary' applications**
  - **e.g. commercial applications such as banking - the new Basel II accords impose risk assessment obligations on banks, *and these include IT risks***
  - **e.g. what is the cost of failures, world-wide, in MS products such as Office?**
- **Gloomy personal view: where it's obvious we *should* do it (e.g. safety) it's (sometimes) too difficult; where we *can* do it, we don't…**

What reliability levels are *required*?

- Most quantitative requirements are from safety-critical systems. Even here the figures vary dramatically.
- Some are extremely stringent
  - e.g. civil aircraft flight control (A320/330/340, B777, etc): 10^{-9} probability of failure per hour
  - e.g. railway signalling and control: 10^{-12} probability of failure per hour!
- Some are quite modest
  - e.g. UK Sizwell nuclear reactor's primary protection system: 10^{-3} probability of failure on demand
  - e.g. surgical robotics: the humans they replace have only modest reliability!
- Seems likely that for *non-safety-critical* systems, the range is just as great

Why uncertainty?

‘Software failures are systematic - if it fails in certain circumstances it will always fail in those circumstances’

- **True. But it is uncertain when those circumstances will occur**
- **There is inherent uncertainty about the process of inputs**
- **‘Systematic’ here does not imply ‘deterministic’**

Why *probabilities*?

There are other ways of dealing with uncertainty: why not use, e.g. Dempster-Shafer, fuzzy/possibility theory, etc

- **Advantages of probability**
  - **advanced and well-understood formalism**
  - **widely accepted and used already, so easy to incorporate into existing frameworks, e.g. risk analysis, e.g. wider safety cases, etc**
- **Problems**
  - **can be very hard to estimate the numbers (see later comments)**
  - **but no easier for other formalisms?**

What drives software unreliability?

'Why doesn't software work perfectly? it's only logic, after all, why don't you just do it right?'

- **Novelty:** **software is often (usually) used to implement radical new functionality**
  - **'if we *can* do it, we *will* do it'**
- **Difficulty:** **some of the problems that software designers have to solve are intrinsically hard**
  - **we routinely build things that would be *unthinkable* in any other technology**
- **Complexity:** **these trends often result in unnecessary complexity in the design solutions**
  - **e.g. not constrained by the reliability implications of *hardware* complexity**

So how bad are things?

If we can't make real programs fault-free, how many faults can we expect?

- **What are achieved fault densities?**
  - **even for safety-critical industries, 1 fault per kLoC is regarded as first class**
    - + **e.g. study of C130J software by UK MoD estimated 1.4 *safety-critical faults* per kLoC (23 per kLoC for non-critical)**
  - **for commercial software, studies show around 30 faults per kLoC**
    - + **Windows XP has 35 MLoC, so >1 million faults!**
- **Is there no good news here…?!**

Many faults means very unreliable?

NOT NECESSARILY!

- **Windows reliability has grown from 300 hours MTBF (with 95/98) to about 3000 hours *despite increased size and complexity* (i.e. more faults)**
- **Operational experience with software in aircraft and automobiles suggest very high reliabilities *can* be achieved**
  - ***After-the-fact estimation* of failure rates, based on very extensive usage:**
    + **Automobiles: Ellims has estimated that no more than 5 deaths per year (and about 300 injuries) caused by software in the UK - suggests about 0.2 x 10^{-6} death/injury failures per hour. Even better *per system* - say 10^{-7}**
    + **Aircraft: *very* few accidents have been attributed to software; Shooman claims, again, about 10^{-7} per hour per system**

Why can software be so reliable…

…when it contains thousands of faults?

- Because many (most?) faults are 'very small'
  - i.e. they occur extremely infrequently during operation
- Adams - more than twenty years ago - examined occurrence rates of faults on large IBM system software: found that more than 60% were '5000-year' bugs
  - i.e. each such bug only showed itself, on average, every 5000 years (across a world-wide population of many users)
  - the systems he studied had many thousands of these faults, but were acceptably reliable in operation

So what's the problem?

Is there a problem?

- Just because large complex programs *can* be very reliable, it does not mean you can assume that a particular one *will* be
  - even if you have successfully produced reliable software in the past, you can't assume from this that a *new* program will be reliable
  - even if some software engineering processes have been successful in the past, this does not *guarantee* they will produce reliable software next time
- So you need to measure how reliable your software *actually is*
- And this assessment needs to be carried out *before* extensive real-life operational use
  - how else can you make a risk assessment?

So how *can* we assess dependability?

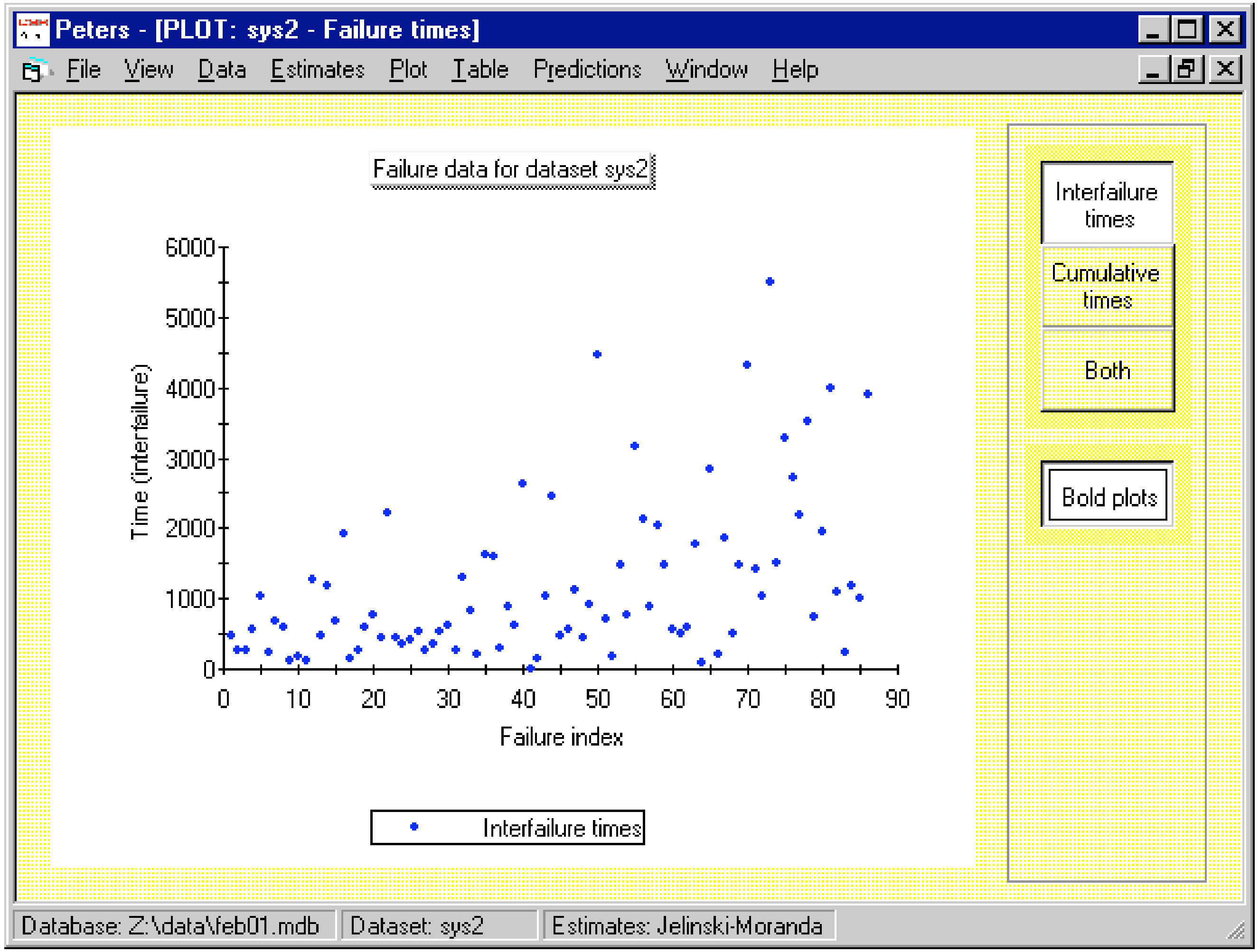
Direct evaluation: Operational testing

- **Statistical methods based upon operational testing are the only means of *direct* evaluation of reliability**
  - allow estimation and prediction of such measures as *mtbf*, *reliability function* (i.e. probability of surviving failure-free for time *t*), *failure rate*, etc
- **They require**
  - means of generating test data that is *statistically representative of operational use*
  - an *oracle* to allow unacceptable ('failed') output to be detected
- **The resulting process of 'acceptable' and 'unacceptable' outputs is used to estimate and predict reliability**

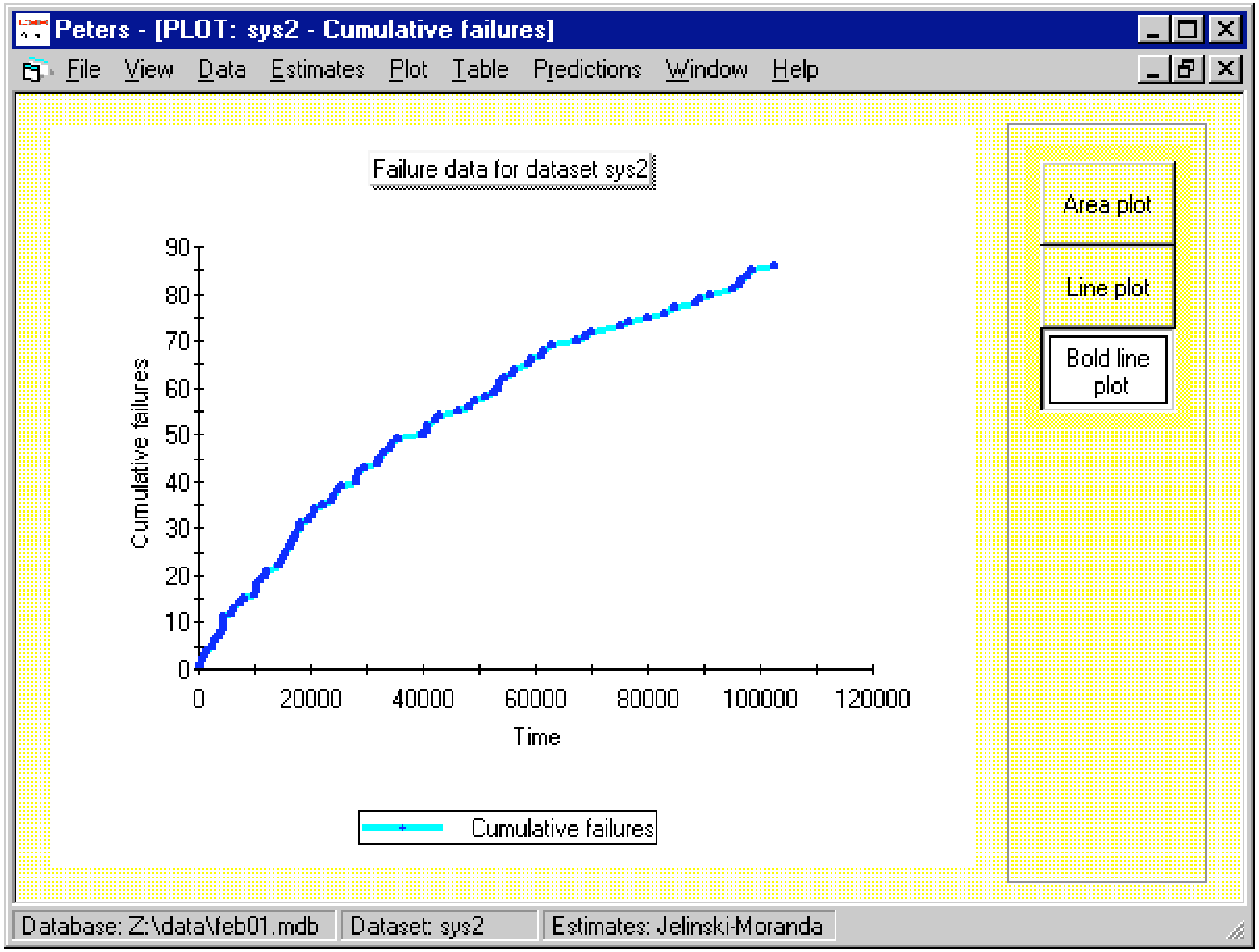
Reliability growth modelling

- **Huge literature developed over the past 25 years**
- **Idea here is that faults are fixed as they are identified in operational testing**
  - **so reliability grows**
- **Many sophisticated probability models have been developed**
  - **aim is to *predict future failure behaviour from observation of the past***
  - **none of the models can be trusted to be accurate *a priori***
  - **but ways of telling whether a model is accurate *in a particular context***
  - **also ways of 'learning from past errors'**
- **Sophisticated tools for doing this**
  - **e.g. our 'PETERS' tool, and several others**
  - **the bottom line here is that you can generally obtain trustworthy results from this approach, *and know that the results are trustworthy***

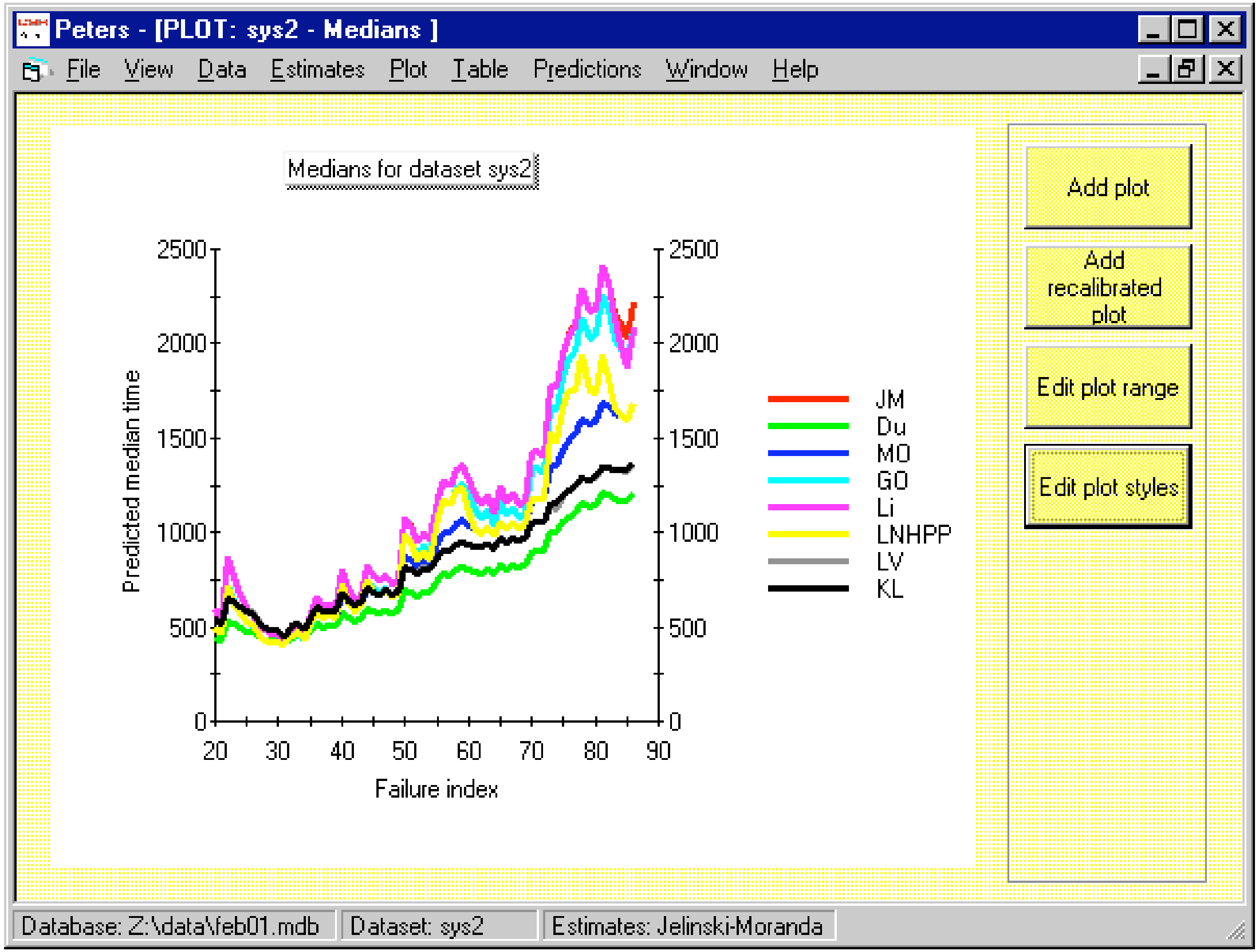
Example of real software failure data



Cumulative plot of same data



Successive *median predictions*



What sort of claims can you make?

It turns out that this kind of evidence of reliability growth from testing only allows quite weak claims

- **e.g. if you want to claim *mtbf* of *x* hours, you will typically need to see 10s or 100s times *x* hours on test**
- **even worse, there is a very strong *law of diminishing returns* operating**
  - **you may end up with *very many very small* faults, each of which is very hard to find**
- **what about the 'best possible' case - where no failures at all are seen in *x* hours of test?**
  - **even here, you can only make modest claims for future behaviour**
    - **e.g. only about a 50:50 chance of seeing further *x* hours failure-free operation before failure.**

So what can we do?

In fact, of course, there is always lots of other information available, in addition to operational test data

- e.g. quality of software engineering process used
- e.g. information from static analysis
- e.g. expert judgement, etc
- we need ways of combining such disparate evidence in formally reasoned *dependability cases* to support dependability claims

Dependability 'case'

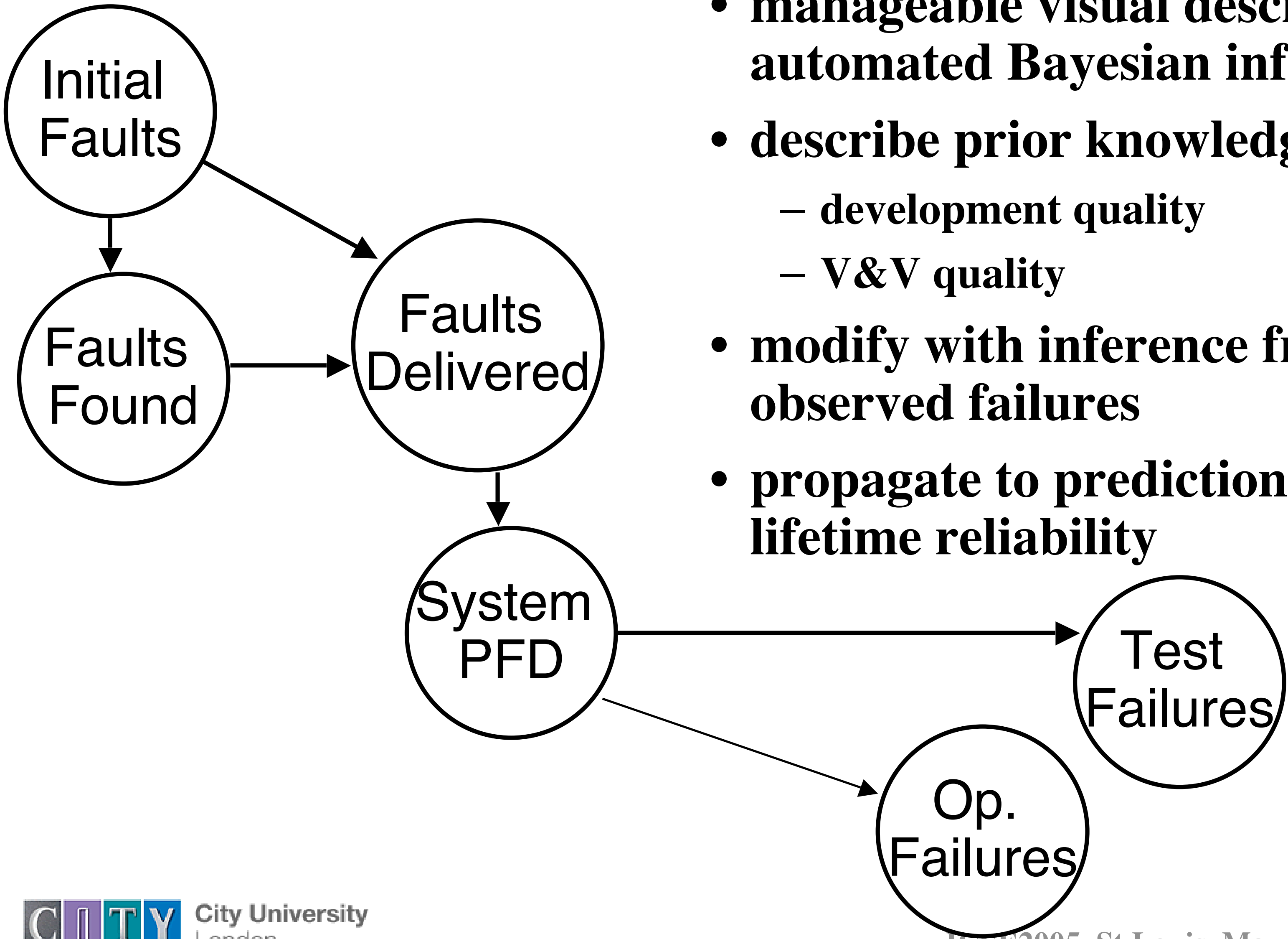
Informally, a dependability case is an argument, based on assumptions and evidence, that supports a dependability claim at a particular level of confidence

- For a particular claim (e.g. the probability of failure on demand of this system is better than 10^{-3}), your confidence in the truth of the claim depends on:
  - strength/weakness of evidence (e.g. the extensiveness of the testing)
  - confidence/doubt in truth of assumptions
- Conjecture: assumption doubt is a harder problem to handle than evidence weakness

But evidence in SE *is* weak

- E.g. software engineering ‘process’ evidence is often used to support product dependability claims
- But it is *very* weak
- We have some evidence to support inference of the kind process->product (e.g. fault count)
- We don’t have much evidence to support inference of the kind process->product->product_reliability (e.g. failure rate)

A promising formalism for ‘cases’: BBNs



- manageable visual description, automated Bayesian inference
- describe prior knowledge about
  - development quality
  - V&V quality
- modify with inference from observed failures
- propagate to prediction about lifetime reliability

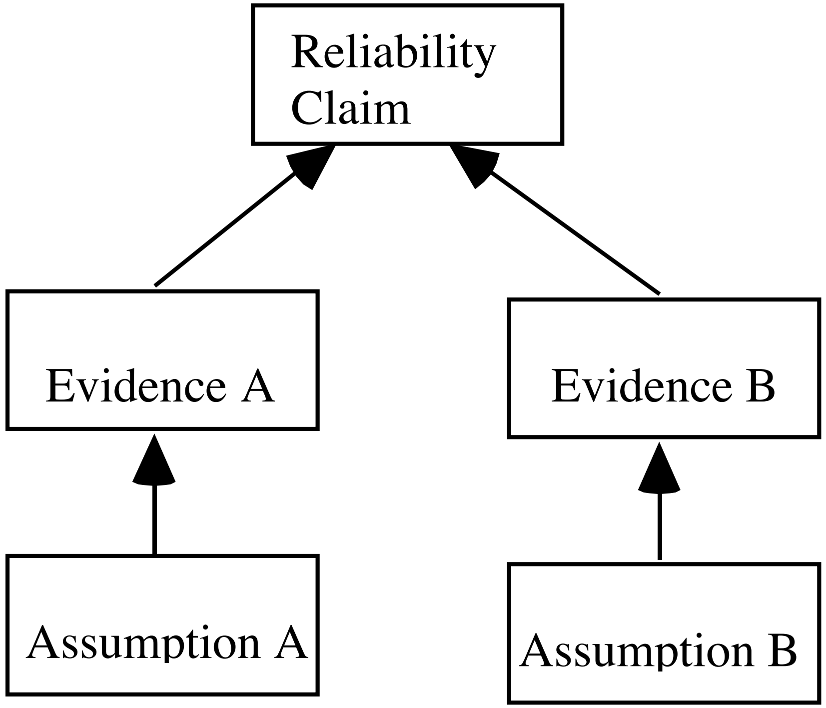
BBNs - advantages and disadvantages

- Advantages
  - powerful aid to reasoning
  - computational algorithms now make ‘proper’ analysis feasible
  - allow expert knowledge to be incorporated (i.e. combine judgement and empirical evidence) - this seems vital for software-based systems
- Limitations/disadvantages
  - permit over-enthusiastic use of expert knowledge!
  - humans are *very* poor at expressing probabilistically their beliefs about uncertainty
  - even the *topologies* of BBNs are not easy to construct
- Current position: use with caution and humility
  - e.g. be more willing to trust simple BBNs than complex ones

Dependability case 'fault tolerance'

Can we borrow ideas from *system* fault tolerance? 'Argument diversity' as analogy of 'system diversity'?

- **Multi-legged arguments to support reliability claim(s)**
  - **leg *B* could overcome evidence weakness and/or assumption doubt in leg *A***
  - **legs need to be *diverse***
  - **advocated in some existing standards (but only informal justification)**
  - **we are trying to formalise this via special BBN structure**
    - + **same 'independence' issues as for systems**



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Summary; and where do we go now?

- The *need* for trustworthy dependability assessment continues - even grows
- For many situations - essentially those with modest requirements - trustworthy evaluation of software reliability is possible
- Great difficulties when required levels are very high
  - the 10^{-9} problem remains unsolved, *and is likely to remain so*
- We need
  - more and better evidence
  - better, more formal, ways of reasoning about disparate evidence in ‘cases’ to support dependability claims
  - in particular, formal treatment of ‘confidence’ in claims

Some new, harder problems loom

We need a much more holistic approach

- **Beyond 'reliability and safety', to incorporate *security***
  - **very little work has been done on problem of (probabilistic) *security assessment***
  - **but some of the reliability techniques probably apply**
  - **need to be able to understand trade-offs**
- **Beyond 'software and computers'**
  - **it's very rare for systems to be purely 'technical' - there are almost *always* humans and organisations involved, and the *whole system* needs to be addressed**
  - **interactions here can be complex and counter-intuitive**
  - **require collaboration with psychologists, sociologists, etc**

THE END

(with no apologies for being so gloomy)