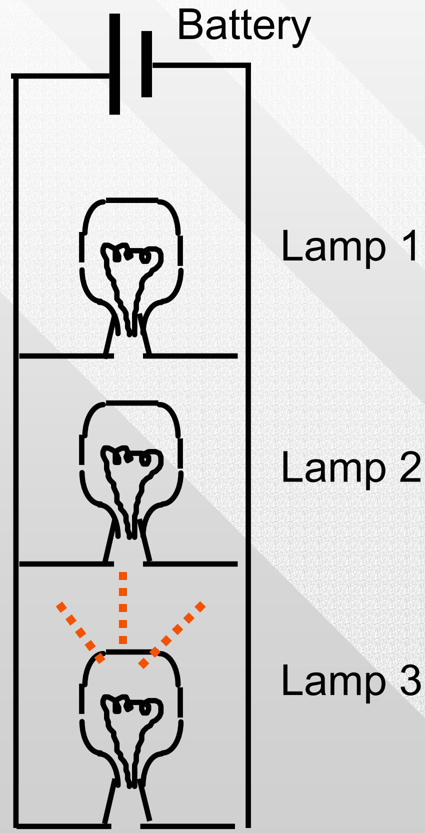
Fault Models

- Good News: what we've seen so far doesn't need them
- Bad News: what we've seen so far can't use them



Conflicts:

B,L1
B,L2
L1,L3
L2,L3

Diagnoses:

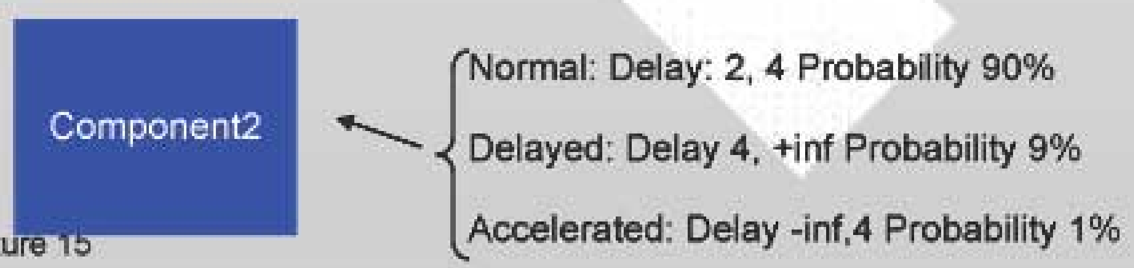
L1,L2

Fault Models

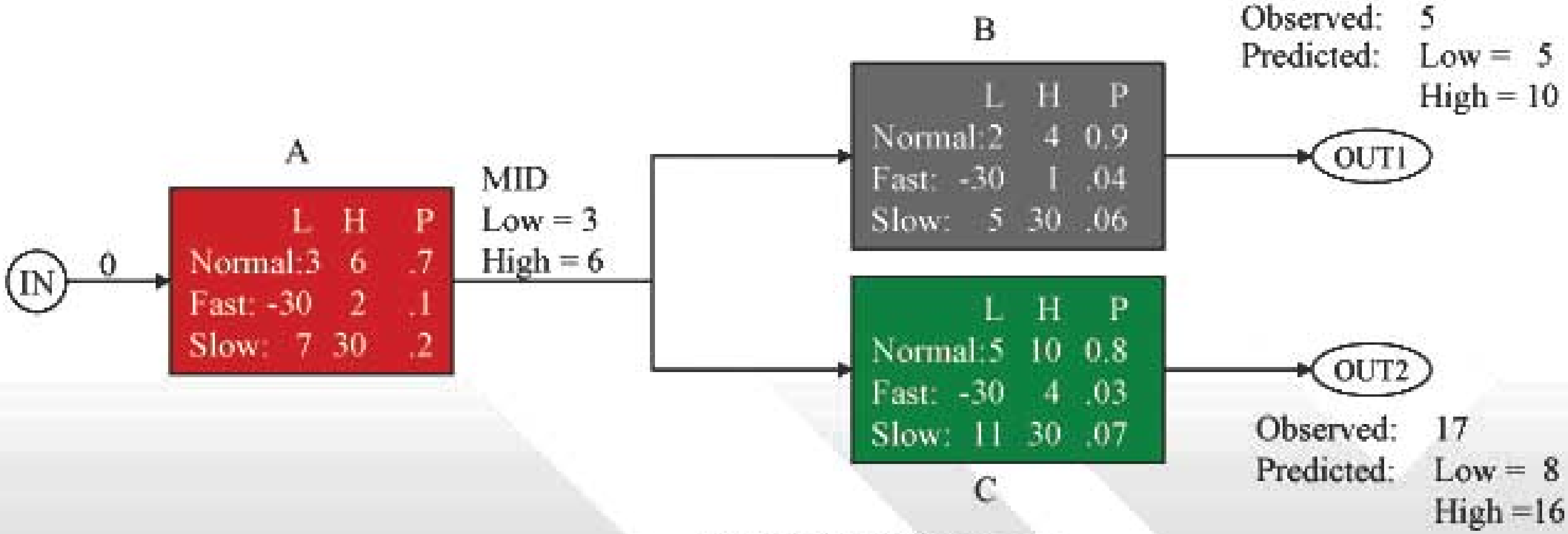
- Extend the notion of fault model to include multiple behavioral modes:
  - Designed behavior (i.e., the *correct* behavior)
  - Known faulty behaviors
  - Residual behavior (i.e. everything *besides* designed and known faults)
  - Their probabilities
- Start with models of correct behavior
- When conflicts exist, substitute a fault model for some member of the conflict set
- Drive the choice of substitution by failure probabilities
  - best diagnosis is most likely set of behavior modes for the various candidates capable of removing all discrepancies
  - i.e., best first search for conflict free set of behavior modes

Adding Failure Models

- In addition to modeling the normal behavior of each component, we can provide models of known abnormal behavior
- Each Model can have an associated probability
- A "leak Model" covering unknown failures/compromises covers residual probabilities.
- Diagnostic task becomes, finding most likely set(s) of models (one model for each component) consistent with the observations.
- Search process is best first search with joint probability as the metric



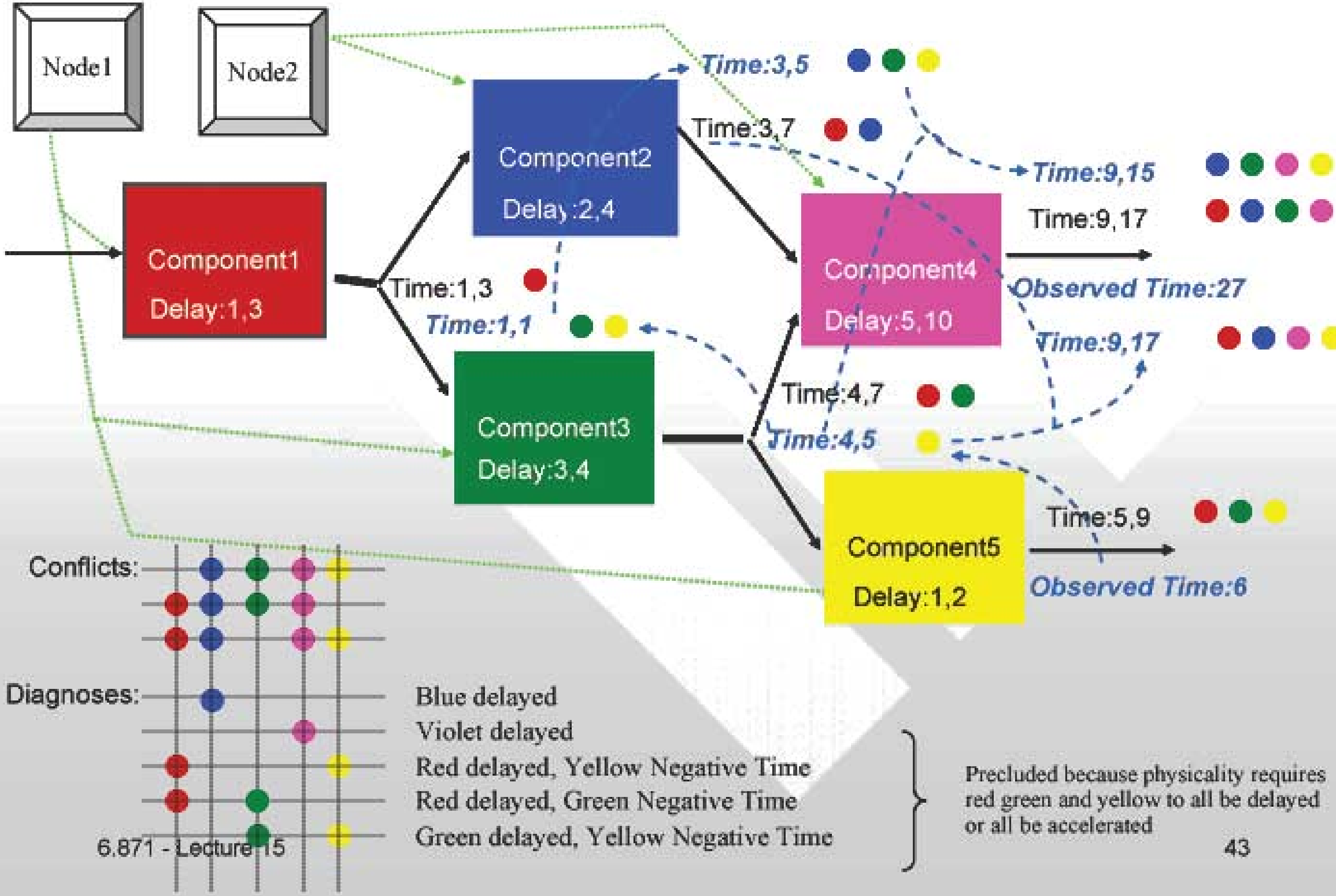
Applying Failure Models



Consistent Diagnoses

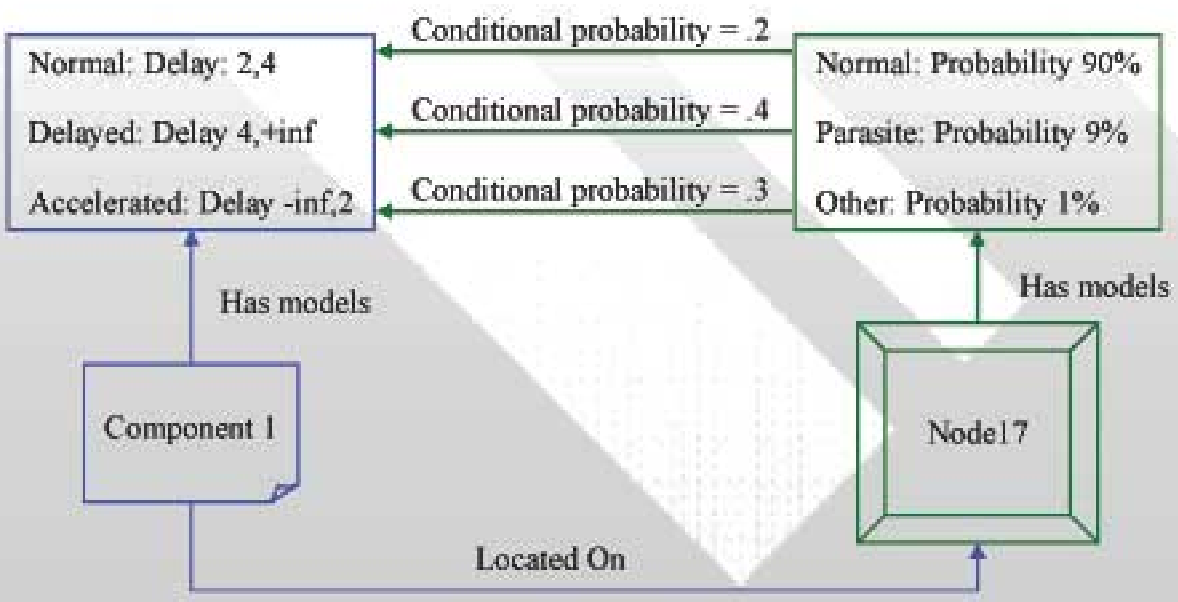
A	B	C	MID Low	MID High	Prob	Explanation
Normal	Normal	Slow	3	3	.04410	C is delayed
Slow	Fast	Normal	7	12	.00640	A Slow, B Masks runs negative!
Fast	Normal	Slow	1	2	.00630	A Fast, C Slower
Normal	Fast	Slow	4	6	.00196	B not too fast, C slow
Fast	Slow	Slow	-30	0	.00042	A Fast, B Masks, C slow
Slow	Fast	Fast	13	30	.00024	A Slow, B Masks, C not masking fast

Computational Models are Coupled through Resource Models

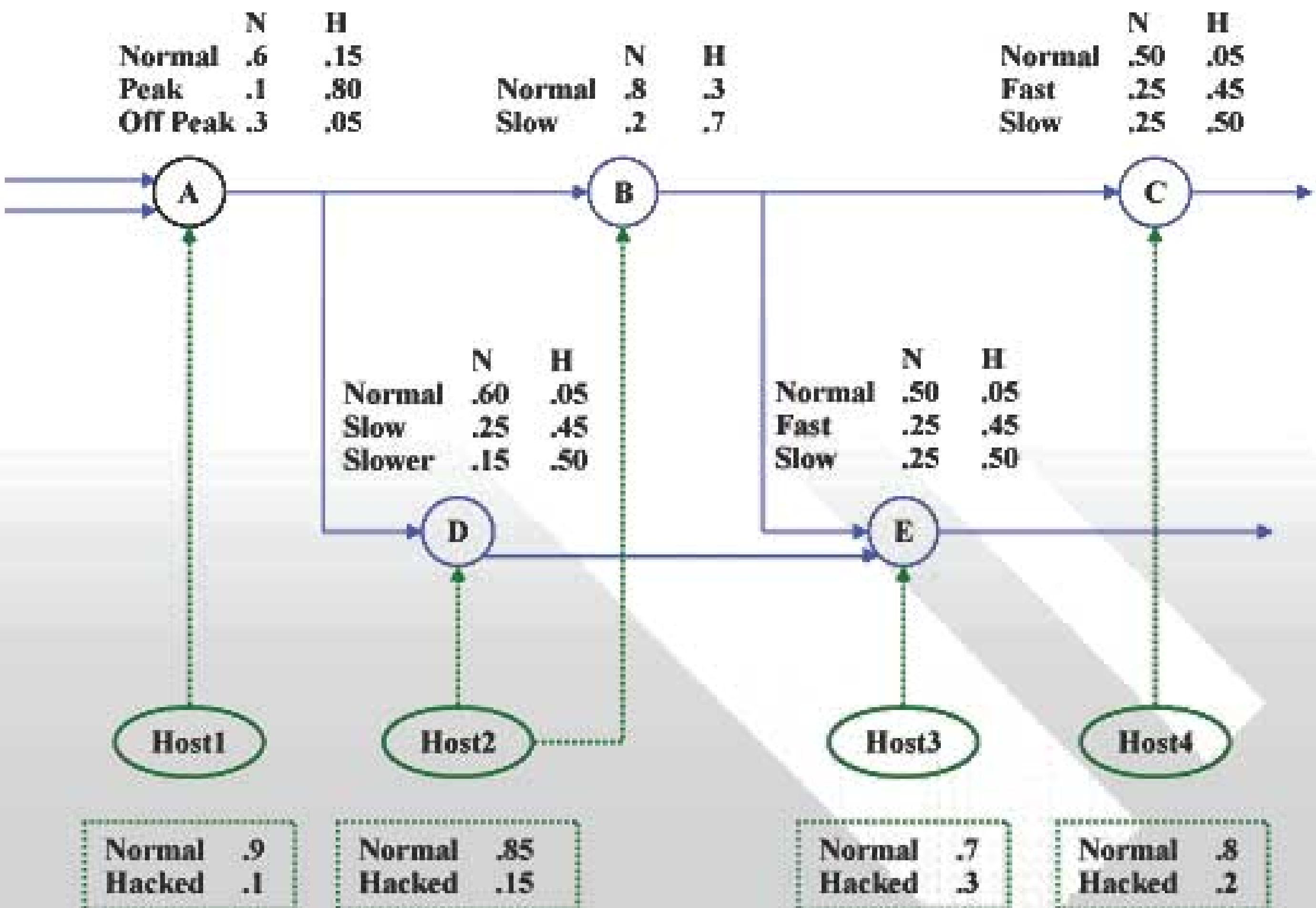


A Multi-Tiered Bayesian Framework

- The model has levels of detail specifying computations, the underlying resources and the mapping of computations to resources
- Each resource has models of its state of compromise
- The modes of the resource models are linked to the modes of the computational models by conditional probabilities
- The Model forms a Bayesian Network

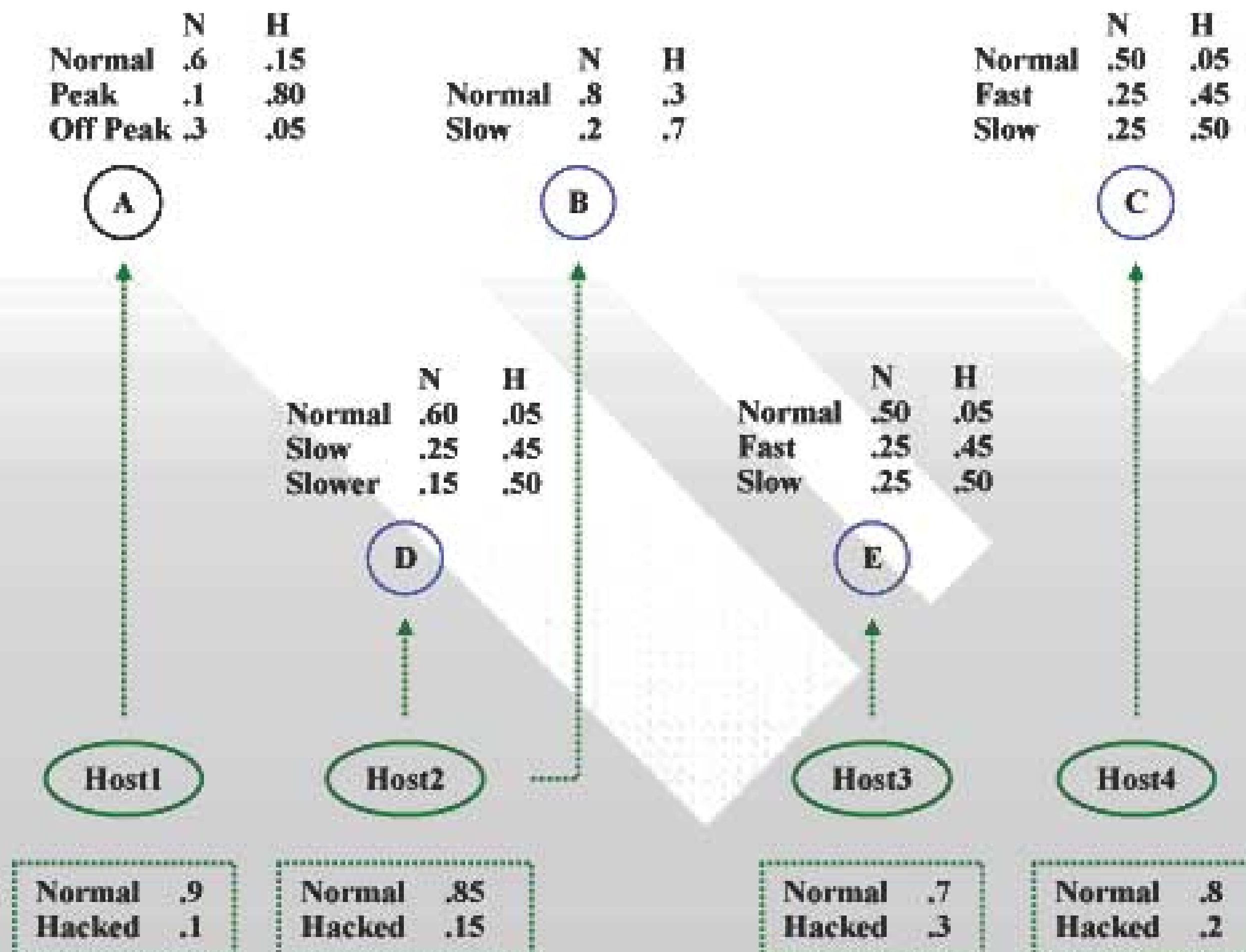


An Example System Description



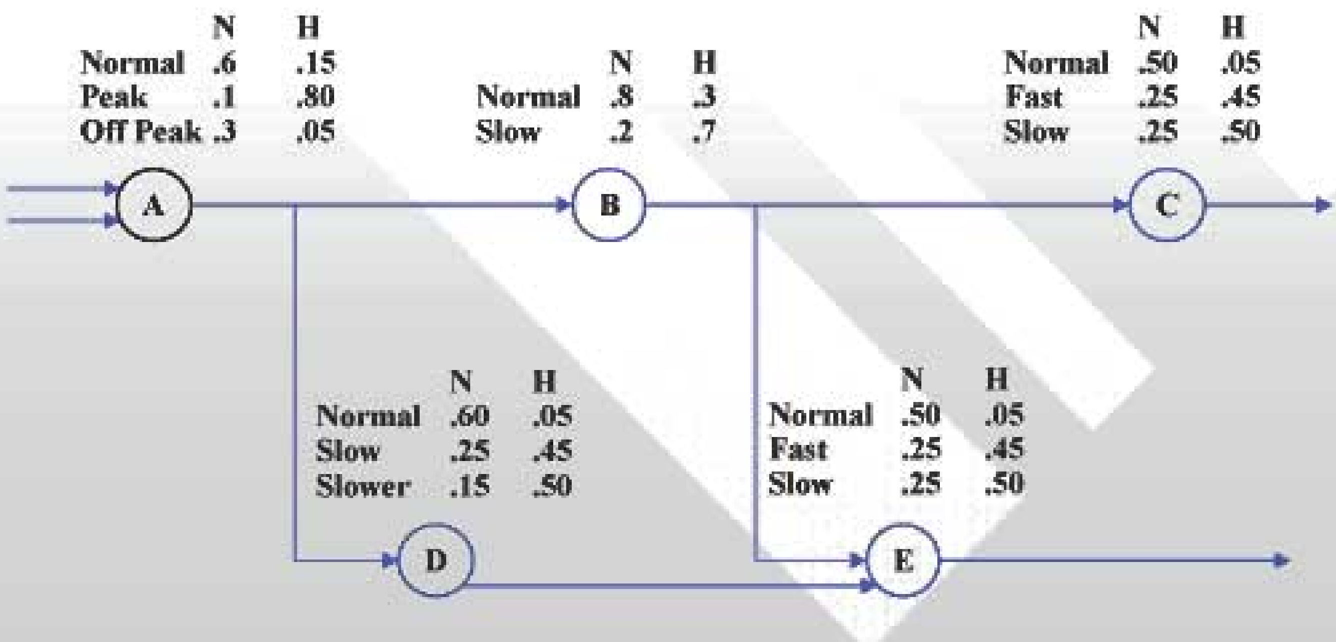
System Description as a Bayesian Network

- The Model can be viewed as a Two-Tiered Bayesian Network
  - Resources with modes
  - Computations with modes
  - Conditional probabilities linking the modes



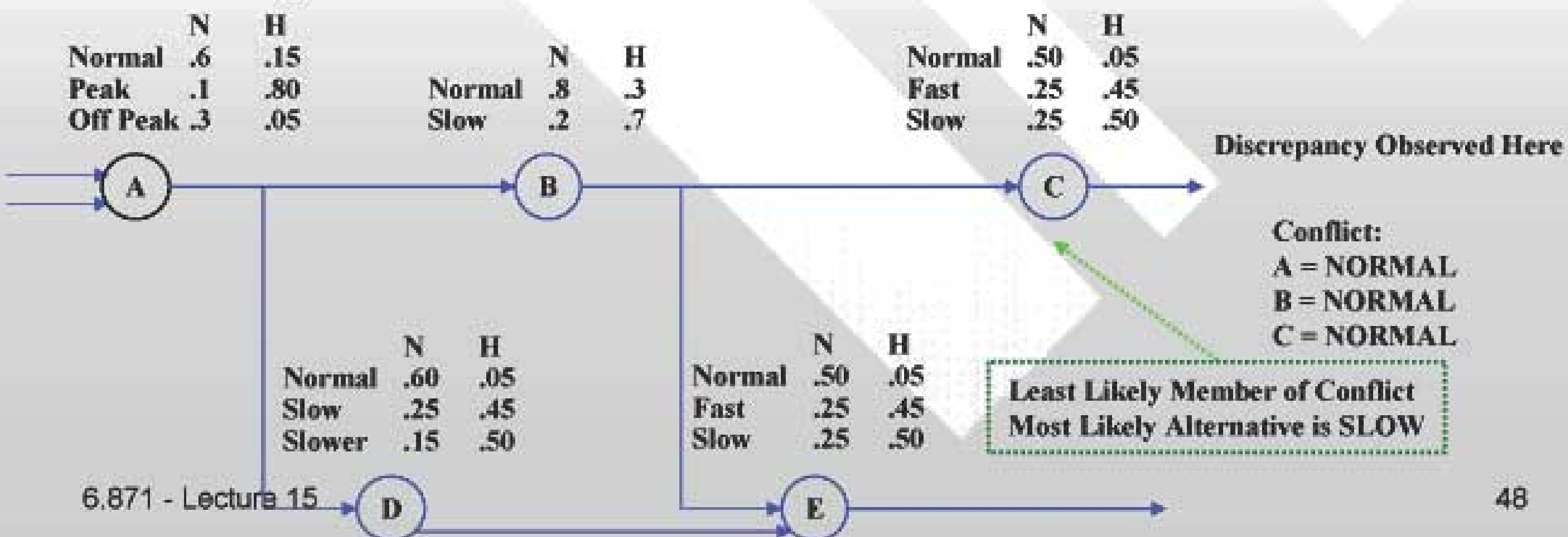
System Description as a MBT Model

- The Model can also be viewed as a MBT model with multiple models per device
  - Each model has behavioral description
- Except the models have <u>conditional</u> probabilities

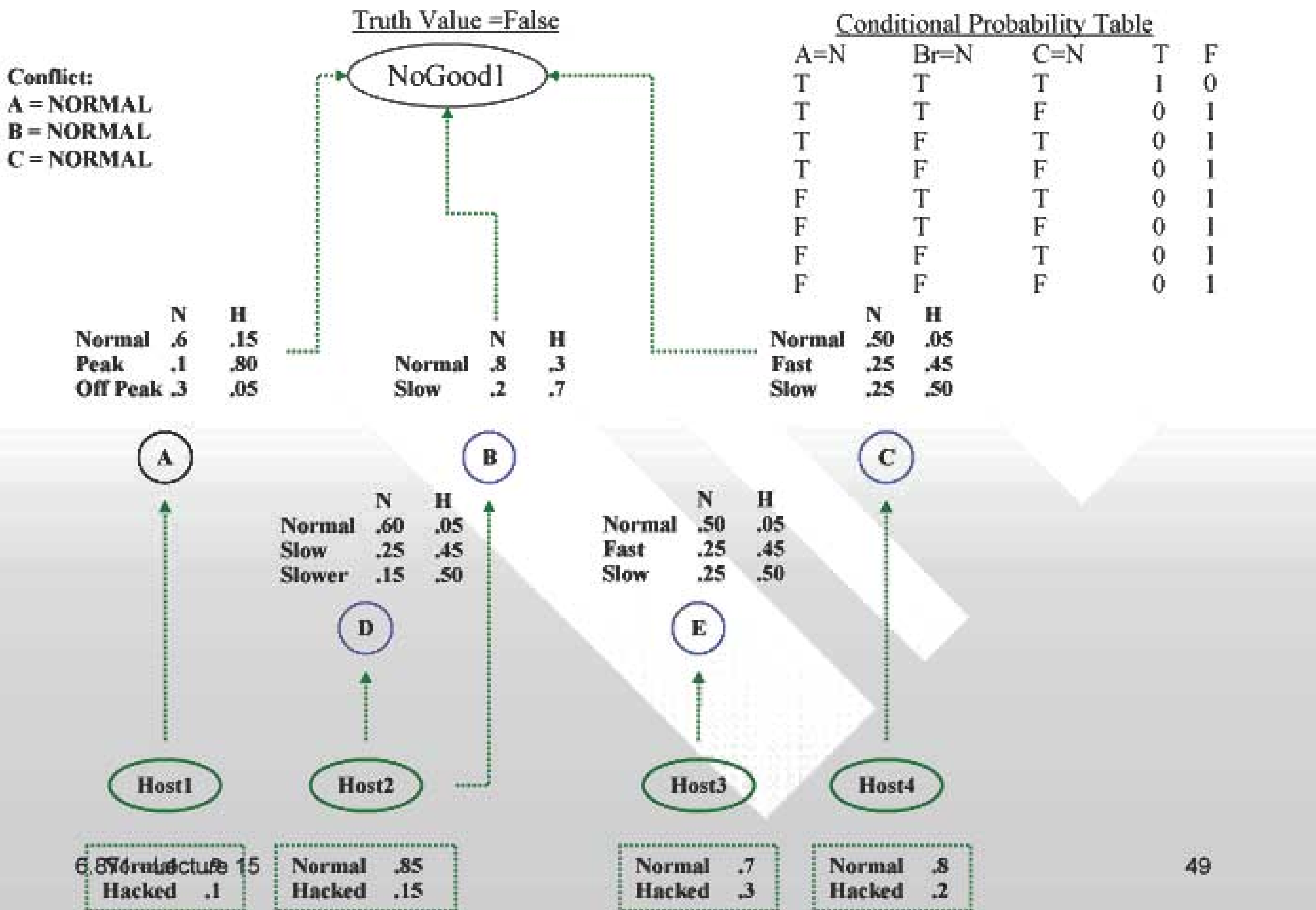


Integrating MBT and Bayesian Reasoning

- Start with each behavioral model in the "normal" state
- Repeat: Check for Consistency of the current model
- If inconsistent,
  - Add a new node to the Bayesian network
    - » This node represents the logical-and of the nodes in the conflict.
    - » It's truth-value is pinned at FALSE.
  - Prune out all possible solutions which are a super-set of the conflict set.
  - Pick another set of models from the remaining solutions
- If consistent, Add to the set of possible diagnoses
- Continue until all inconsistent sets of models are found
- Solve the Bayesian network



Adding the Conflict to the Bayesian Network



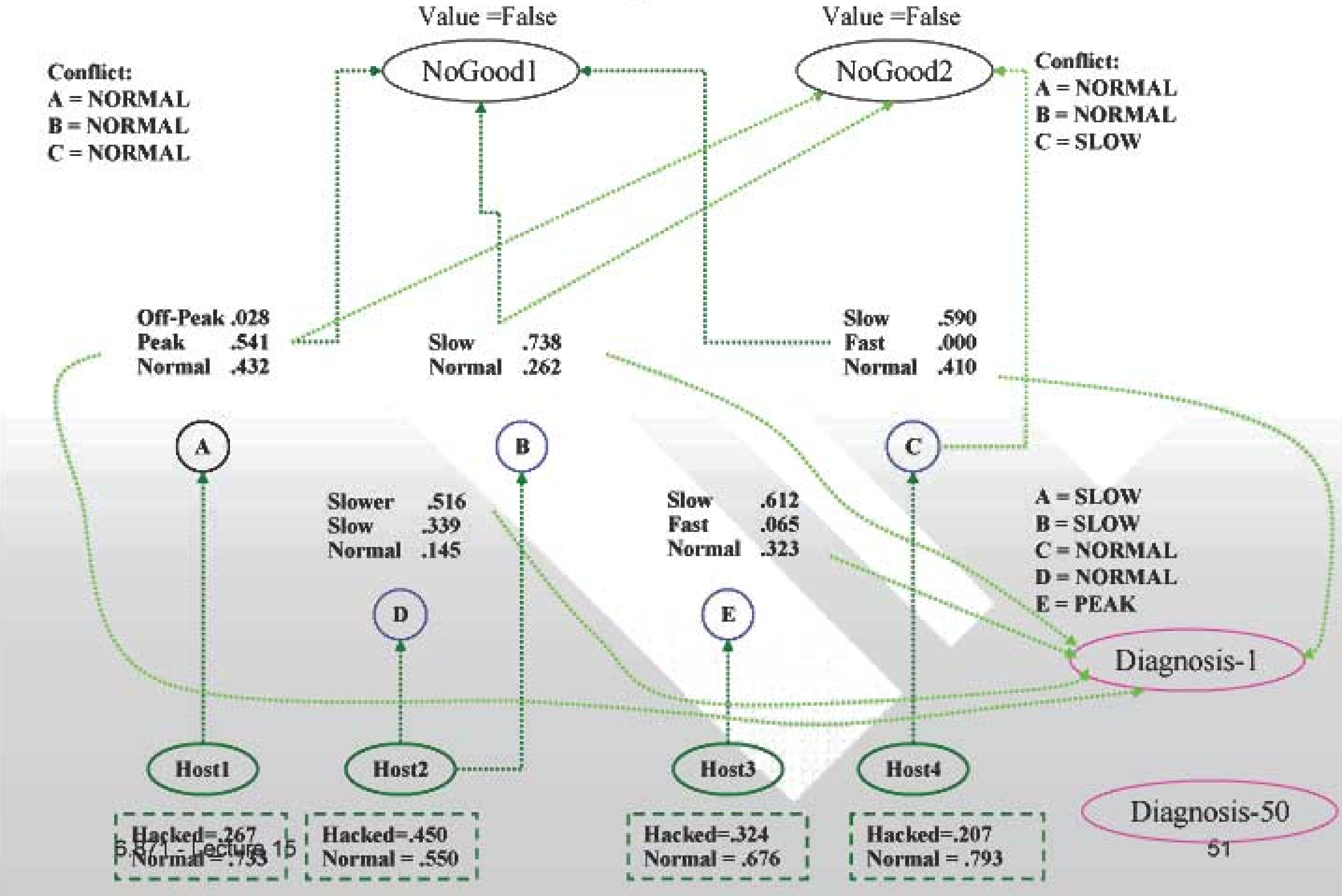
Conditional Probability Table

A=N	Br=N	C=N	T	F
T	T	T	1	0
T	T	F	0	1
T	F	T	0	1
T	F	F	0	1
F	T	T	0	1
F	T	F	0	1
F	F	T	0	1
F	F	F	0	1

Integrating MBT and Bayesian Reasoning (2)

- Repeat Finding all conflicts and adding them to the Bayesian Net.
- Solve the network again.
  - The posterior probabilities of the underlying resource models tell you how likely each model is.
  - These probabilities should inform the trust-model and lead to Updated Priors and guide resource selection.
  - The Posterior probabilities of the computational models tell you how likely each model is. This should guide recovery.
- All remaining non-conflicting combination of models are possible diagnoses
  - Create a conjunction node for each possible diagnosis and add the new node to the Bayesian Network (call this a diagnosis node)
- Finding most likely diagnoses:
  - Bias selection of next component model by current model probabilities

The Final Bayesian Network

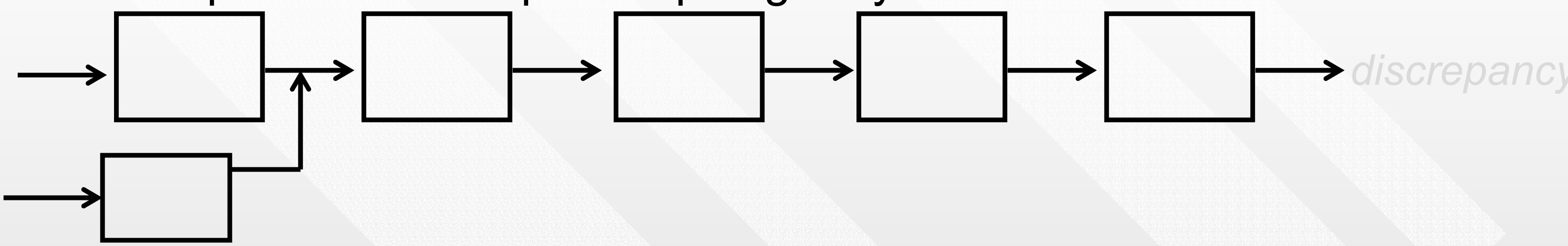


Three Fundamental Problems

- Hypothesis Generation
  - Given a symptom, which components could have produced it?
- Hypothesis Testing
  - Which components could have failed to account for all observations?
- Hypothesis Discrimination
  - What additional information should we acquire to distinguish among the remaining candidates?

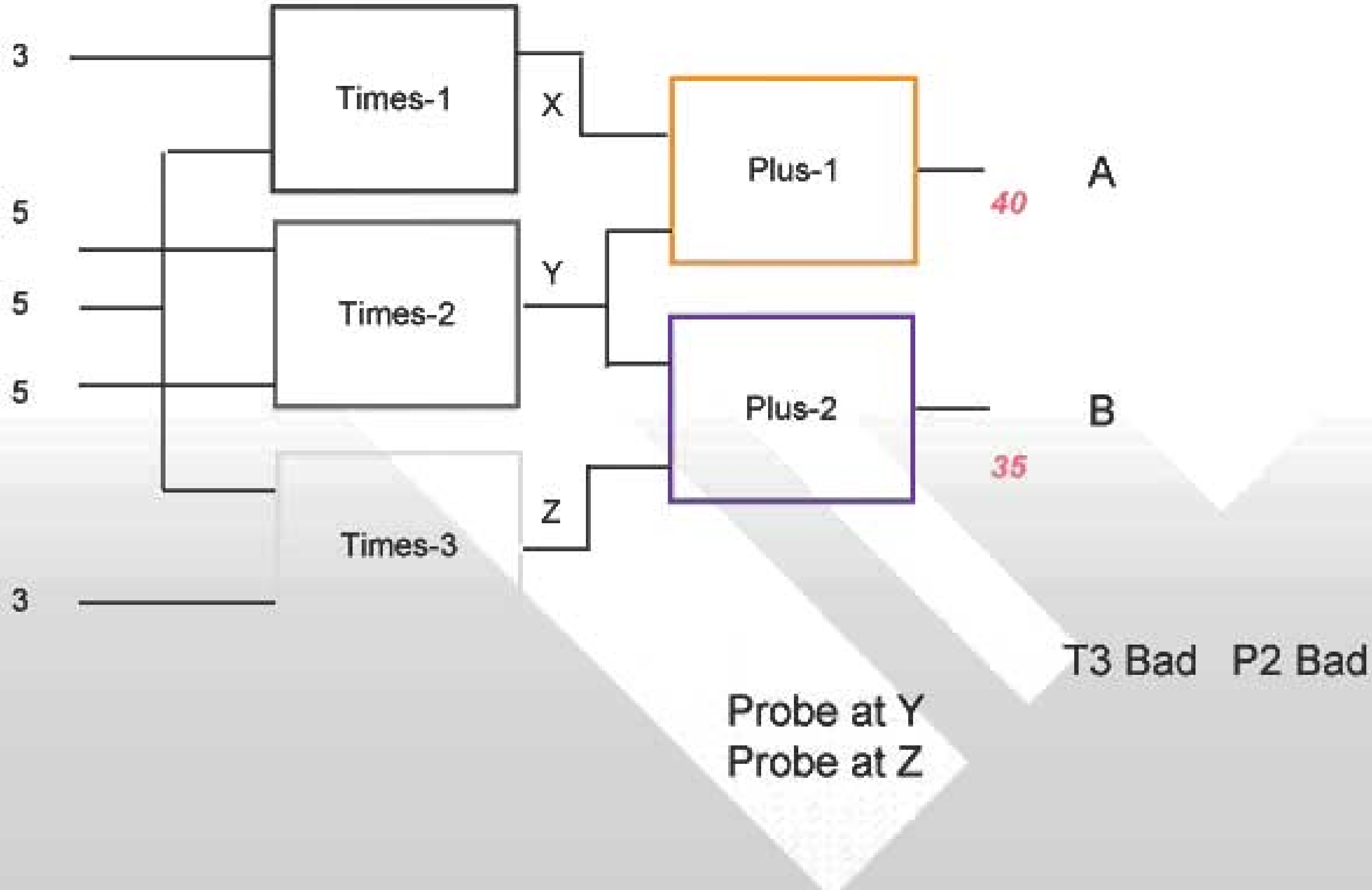
Probing and Testing

- Purely structural
  - Follow discrepancies upstream (guided probe)
  - Split candidate space topologically

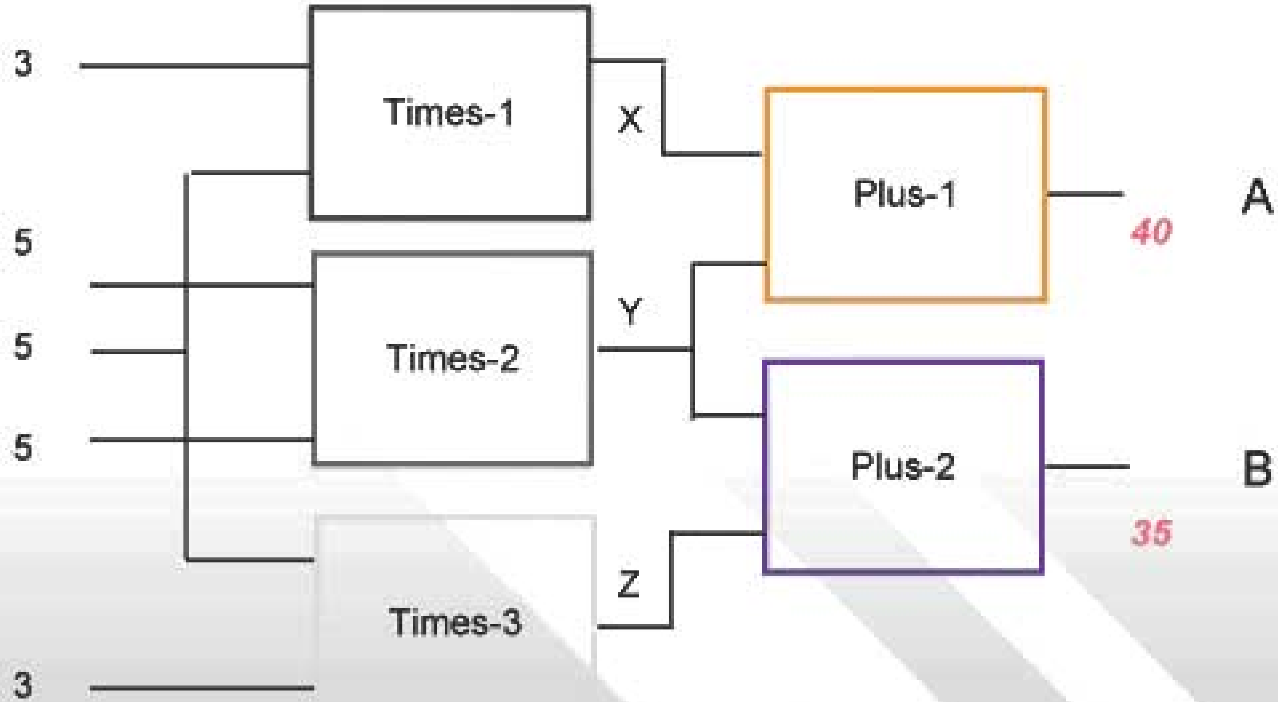


- Add behavioral information:
  - Split topologically: G&T on the sub-problem
  - Predict consequences of candidate malfunction; probe where it is most informative.

Informative Probes



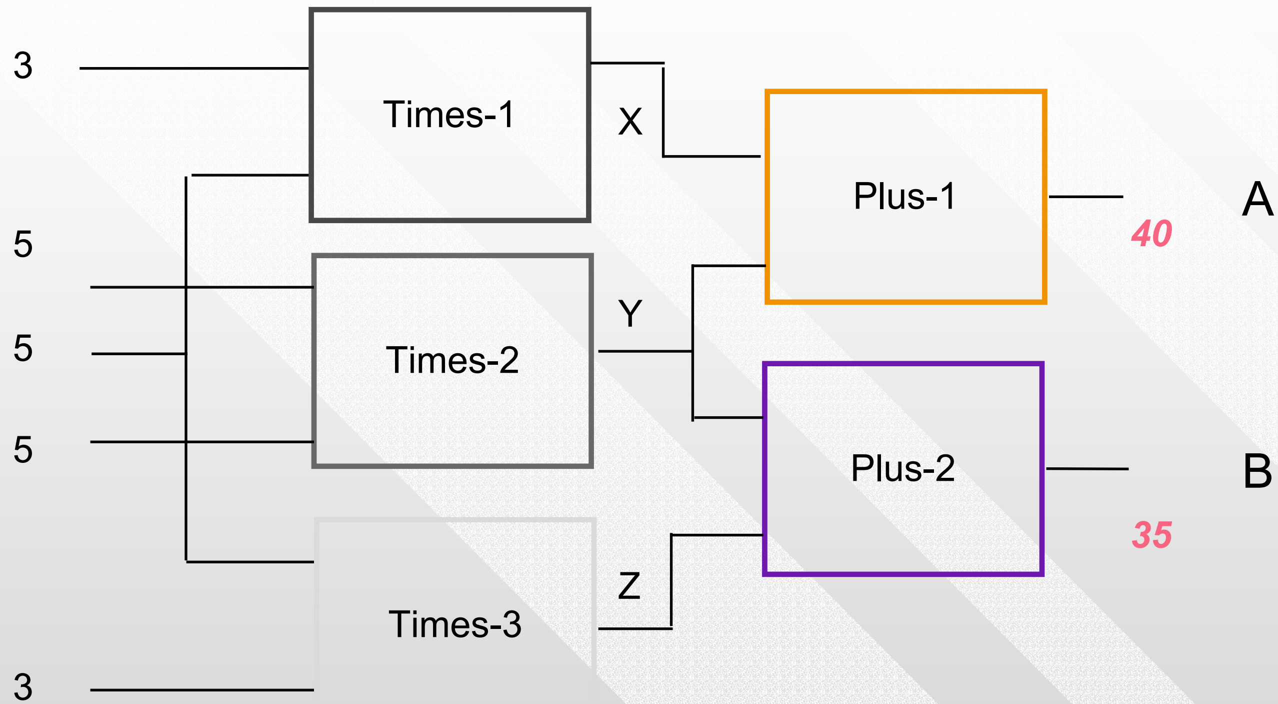
Informative Probes



Probe at Y
Probe at Z

T3 Bad	P2 Bad
25	25

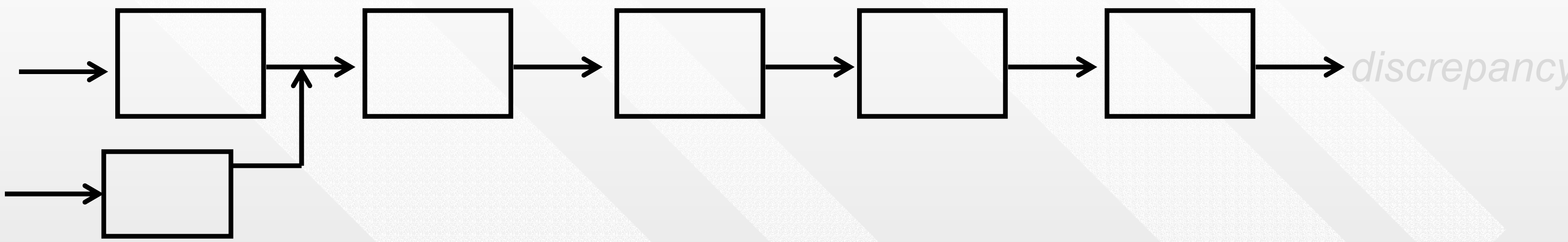
Informative Probes



	T3 Bad	P2 Bad
Probe at Y	25	25
Probe at Z	10	15

Probing and Testing

- Purely structural
  - Follow discrepancies upstream (guided probe)
  - Split candidate space topologically

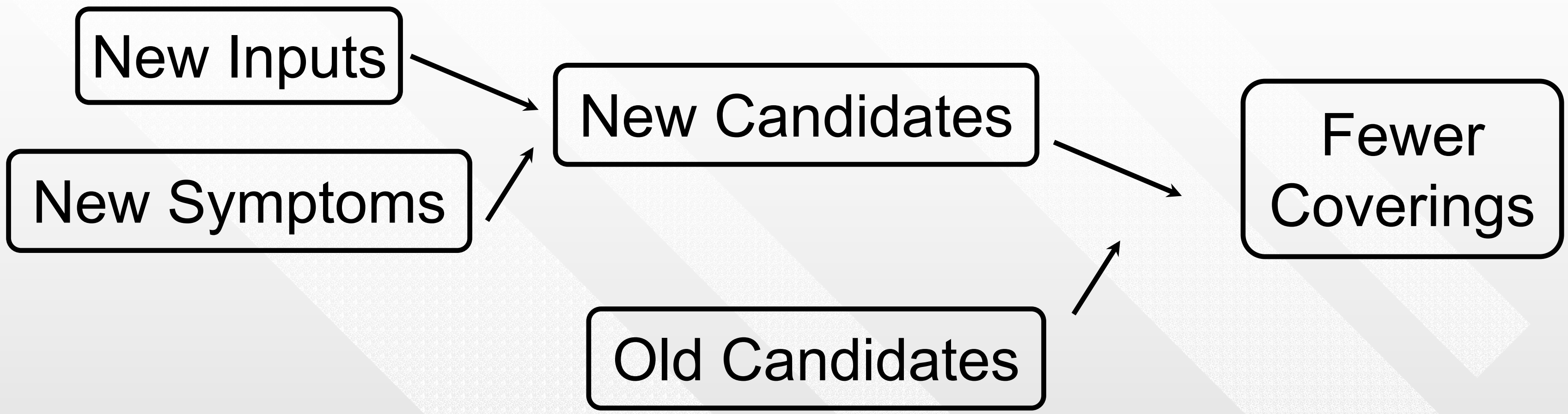


- Add behavioral information:
  - Split topologically: G&T on the sub-problem
  - Predict consequences of candidate malfunction; probe where it is most informative.

- Add failure probabilities
  - Cost-benefit calculation using maximum entropy methods

Assumption: Computation is cheap compared to probing (think of chips)

Testing

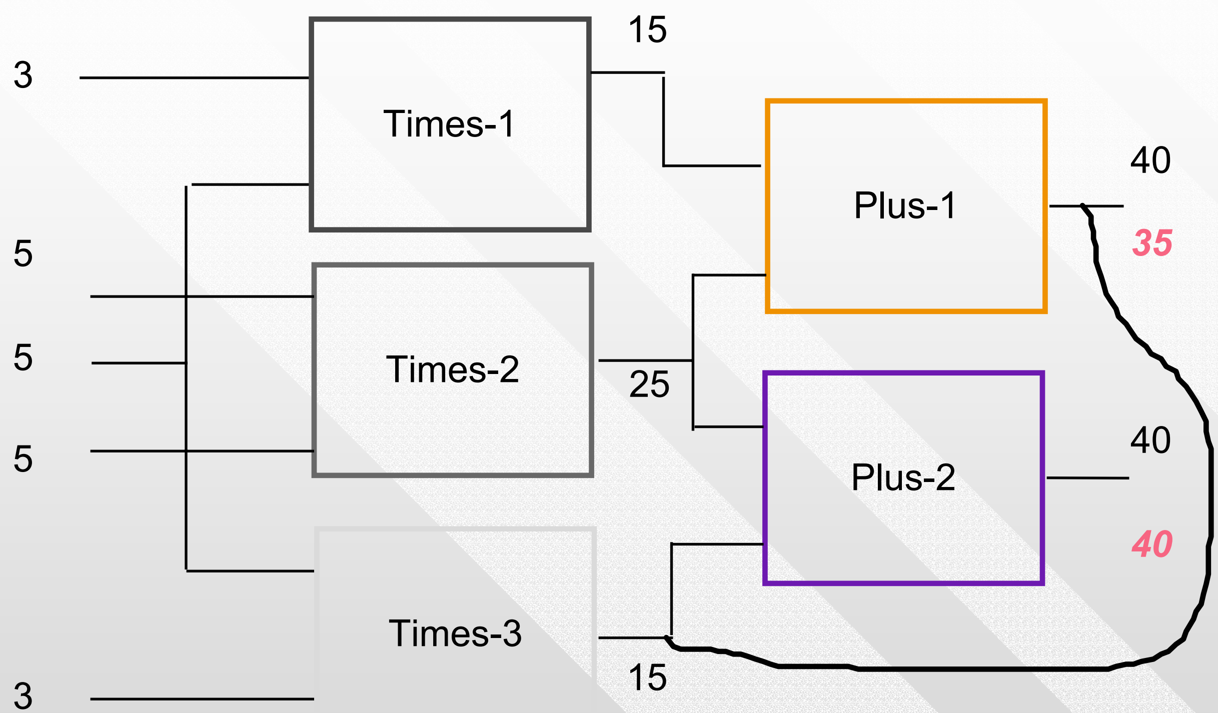


- General problem is very hard
- Basic insight: don't use members of candidate sets to route signals (i.e. use only parts believed to be good)

Difficulties

- Model based reasoning is only as good as the model
- Tension between completeness of description and tractability of reasoning.
- Scaling: size alone isn't the issue (but it is an issue)
- Complex behavior is an issue
  - VCR, ALU, Pentium, PowerPC, Disk Controller
  - This requires new vocabulary, new abstractions
  - Temporally coarse descriptions are often important
    - » Memory and state are hard to model
    - » Temporally coarse representations can hide the state usefully

The Model Isn't How It Is



The Model Isn't How It Is

- Because it shouldn't be that way
  - bridge faults, assembly error
- Because of unexpected pathways of interaction
  - eg heat, radiation
- In practice, by our choices
  - deciding not to represent each individual wire segment
- In principle: it's impossible

Complexity vs Completeness

- Any simplifying assumption risks incompleteness

- Make too few assumptions and
  - diagnosis becomes indiscriminate
  - drown in complexity, ambiguity

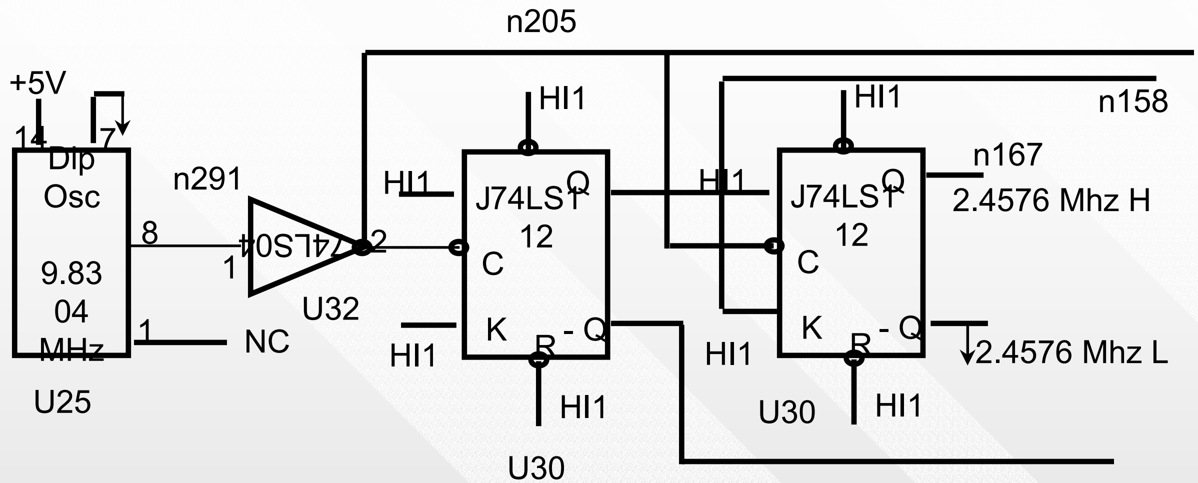
Model Selection and Formulation Is a Key Problem

- There are no assumption-free representations
  - perhaps we can use more than one
- Completeness and complexity conflict
  - we'll need to choose judiciously
- Basic question: *whence the model?*
  How do we know how to think about the device?

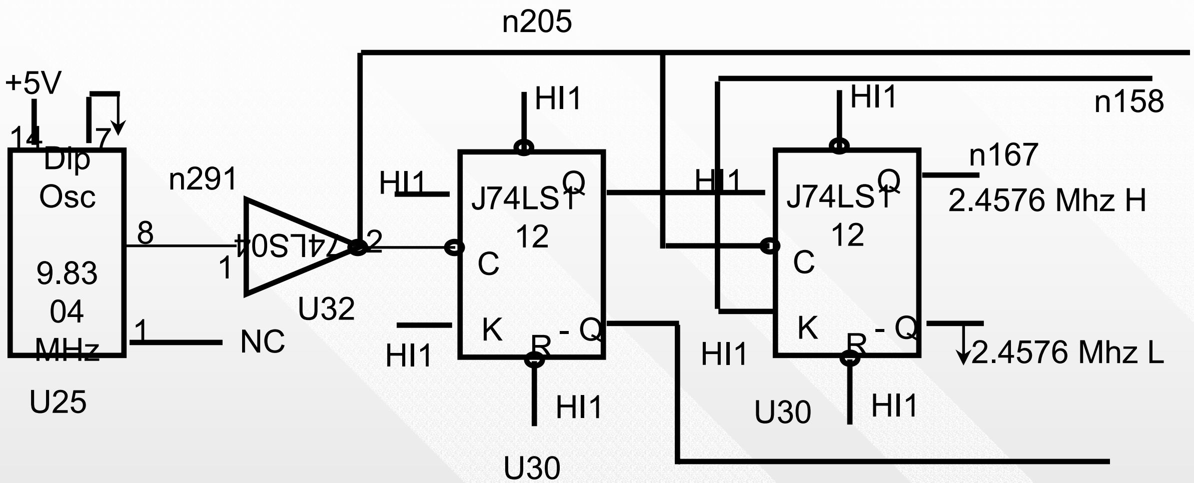
Another Problem: Complex Behavior

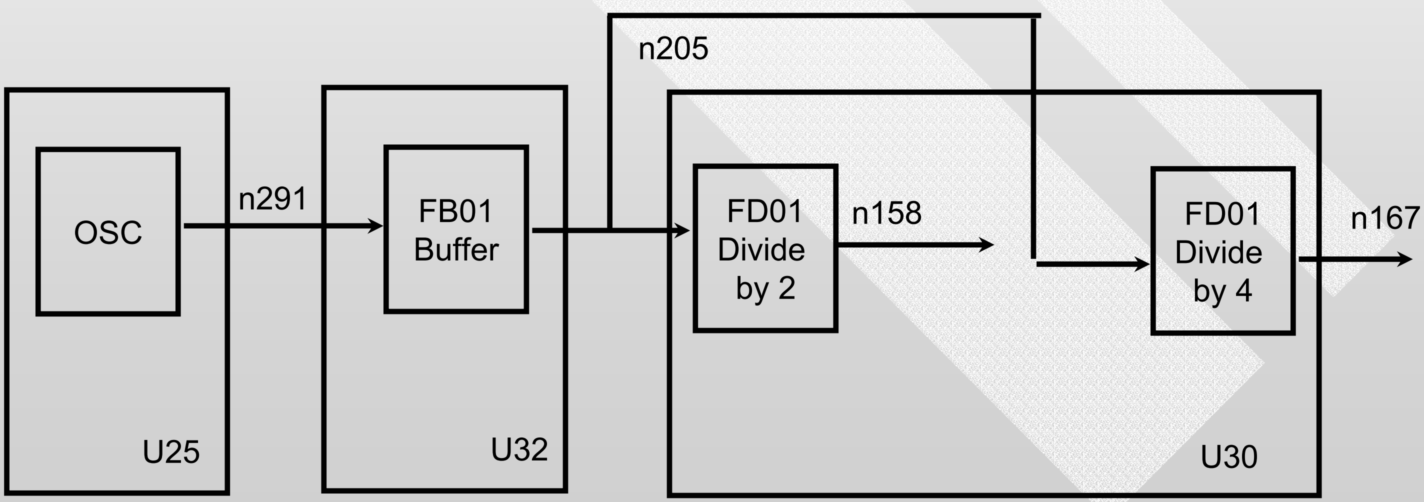
- An engineer plugs in a broken circuit board, makes a half dozen simple probes with an oscilloscope, and after ten minutes ends up swapping a chip, which fixes the problem.
- A model-based troubleshooting program spends a day simulating the expected behavior of the same misbehaving board, and requests that a logic analyzer be used to capture a certain subset of the signals. After some hours of computation, it concludes that any of the 40 chips or 400 wires on the board could be responsible for the misbehavior.
- Why?

The Two Different Approaches to MBT



The Two Different Approaches to MBT





If n167 is “flat” then U25, U32 and U30 form a conflict. But Oscillators tend to fail more frequently, so U25 is more likely to be broken. A probe of n291 is advised.

More (detail) is Worse

- The naïve approach suggests a detailed, step by step simulation of the device as the first phase of the diagnosis.
- For a reasonable circuit with internal states, all interesting behavior exists over the time span of many thousands to millions of clock cycles.
- The naïve approach fails to capture the right functional abstractions
  - Devices: Central controller
  - Behavior: Frequency
    - » Changing
    - » Stable

The Problems to be Faced

- Models are incomplete.
- Observations are costly.
- Observations are incomplete and imprecise.
- Prediction is costly.
- Prediction is incomplete.

How to Address these Problems

- Choose the representation of primitive elements and connections so as to sacrifice completeness for efficiency.
  - Treat physically separate components with indistinguishable failure modes as one component.
  - Treat devices whose failure requires the same repair as one device.
  - Don't represent very unlikely failure modes
- Describe signals in a way which is easy to observe.
- Represent the likelihood of failure modes.
- Use temporally abstract description of signals.
- Use multiple levels of behavioral abstraction.

Principles of Modeling

- Components in the *physical representation* should correspond to the possible repairs.

- Components in the *functional representation* should facilitate behavioral abstraction.

Principles of Modeling

- Components' behavioral representation should employ features that are easy to observe.
- A temporally coarse description is better than no description.
- A sequential circuit should be encapsulated into a single component whose behavior can be described in a temporally coarse manner.
- Represent a failure mode if it has a high likelihood.
- Represent a failure mode if the misbehavior is drastically simpler than the normal behavior

Conclusions

- General purpose paradigm (with variations)
- Largely domain independent
- Successfully employed in practice
- Major research issues are in modeling, not reasoning methods
  – complex behavior
  – model selection
  – model formulation