Applications of Artificial Intelligence

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Chapter 4:
Knowledge-Based Systems

4.3: Model-Based Reasoning

3. Model-Based Diagnosis

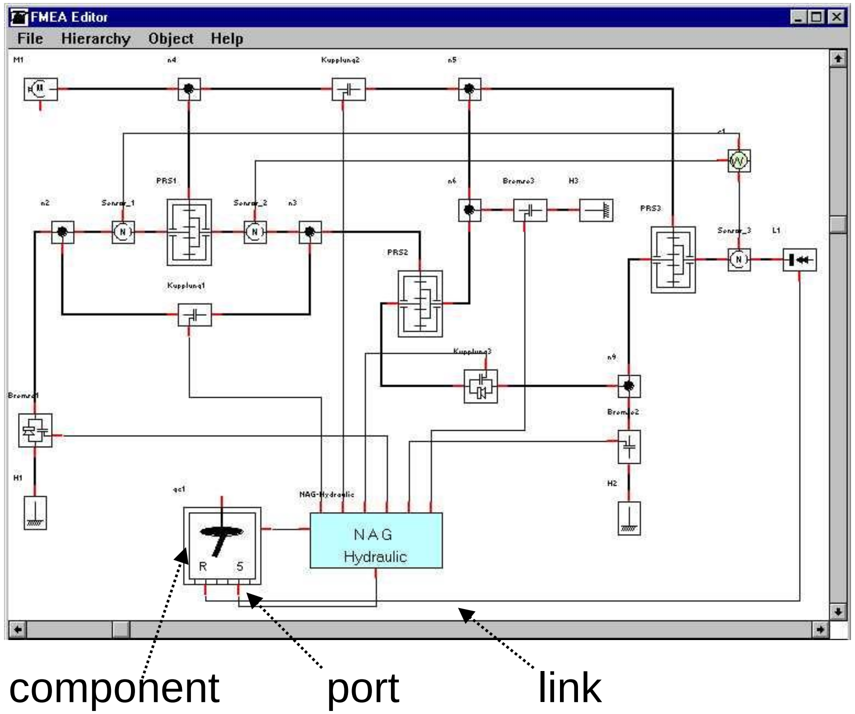
Goal:

- fast knowledge acquisition
- exact and provable solution of problem solver

Challenge:

- reasonable response time of problem solver at run time

3. Model-Based Diagnosis



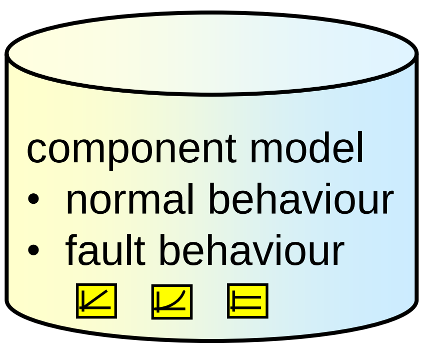
<u>System model</u>:

Which components of which type are connected in which way?

➔ ***available from CAD data***

<u>Component models</u>:

How do values depend on each other lying at ports of the component?



➔ ***to be modeled once per component <u>type</u>***

➔***Model is reusable for all systems containing components of this type.***

3. Model-Based Diagnosis

Input to knowledge base:

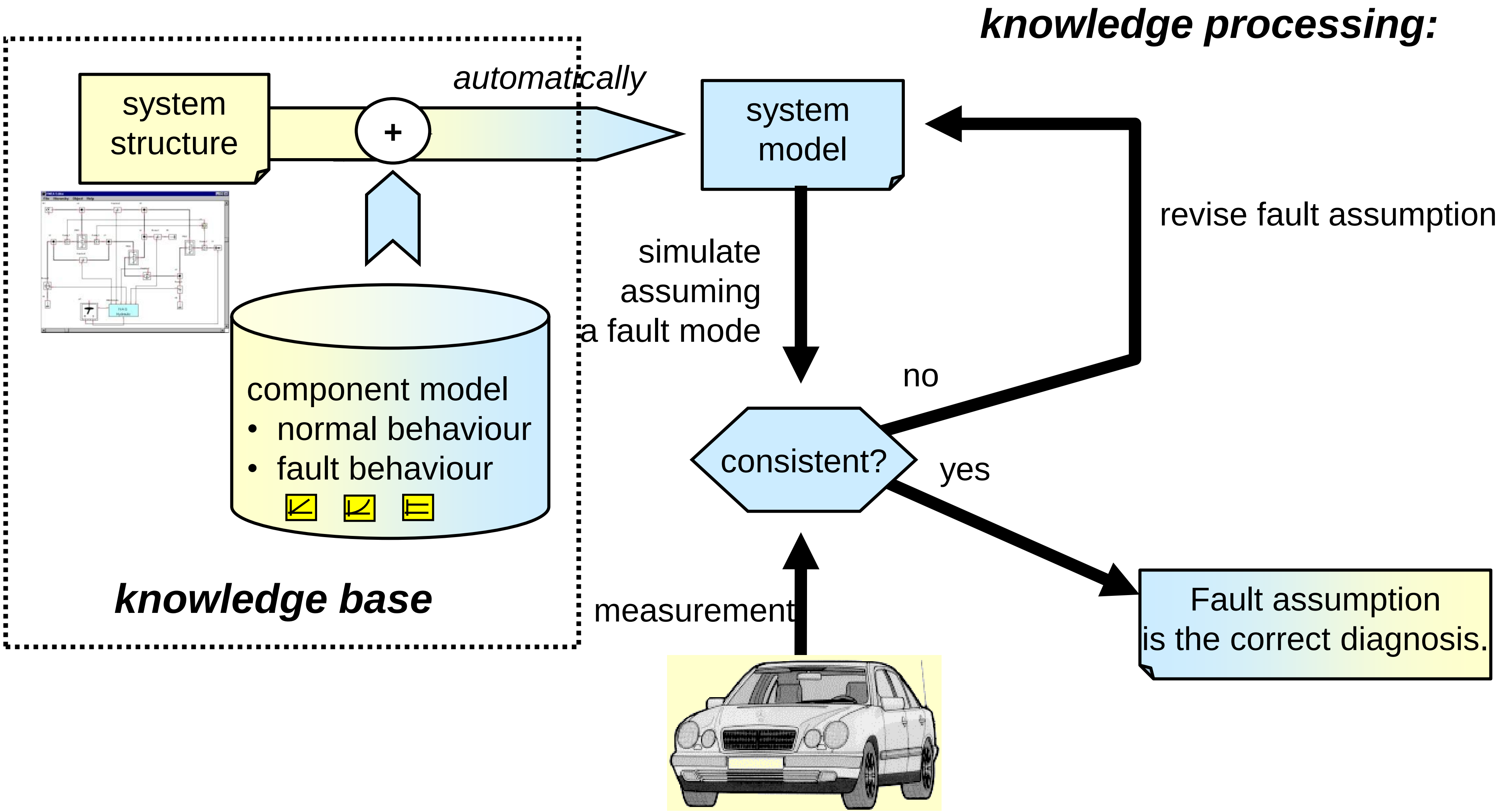
- system model: hierarchical structure of the system (+ how the components are connected)
- component models

Structure of knowledge base:

- constraint network (assembled automatically)
- structured by:
  - assigning constraints to components and ports
  - assigning variables to components and ports

3. Model-Based Diagnosis

Base functionality: Conflict driven search



3. Model-Based Diagnosis

Base functionality: Finding consistent assumptions

GDE 1987: *The* prototype for model-based diagnosis

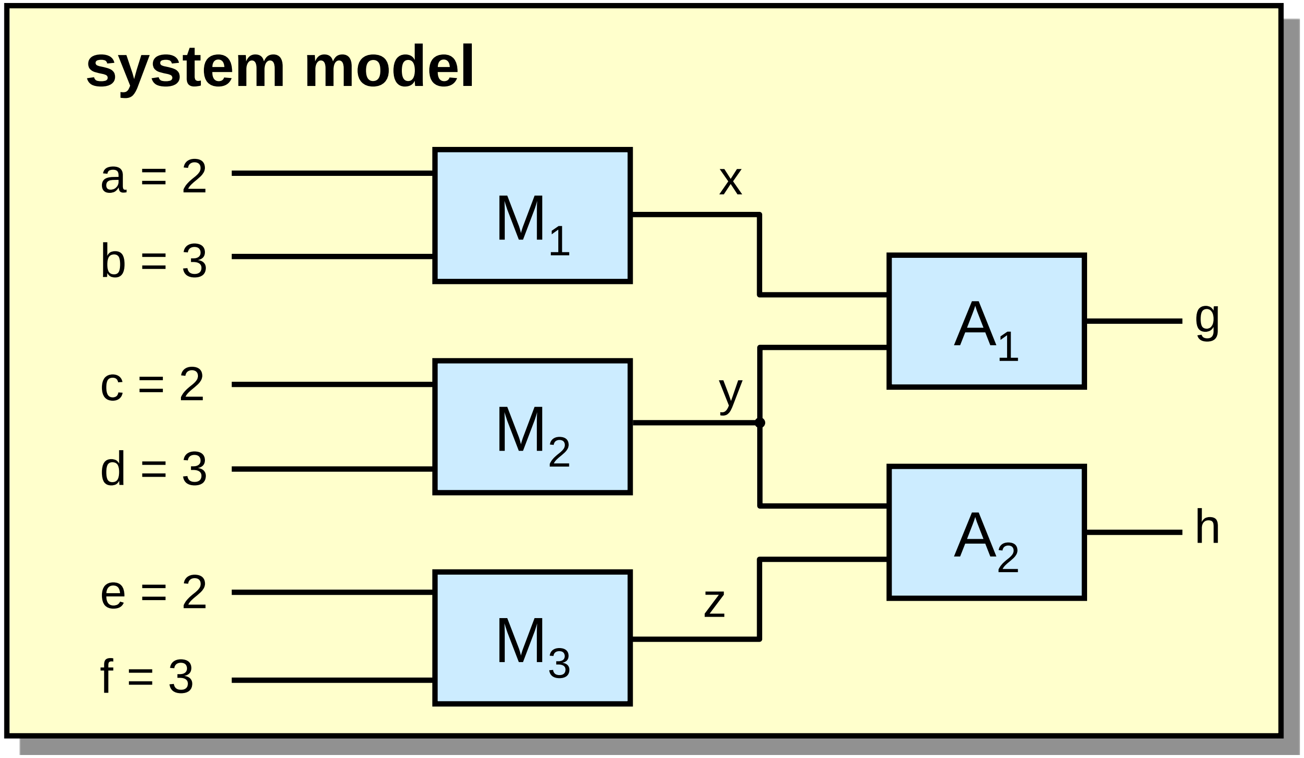
Problem:

- ‚brute-force' Simulation of ***all*** fault assumptions combinatorically not feasible

Idea: General Diagnostic Engine GDE, deKleer & Williams 1987

- intelligent search in the space of all fault assumptions
- uses inconsistent assumptions for pruning the search space
- base principle: conflict-driven search

GDE - Example

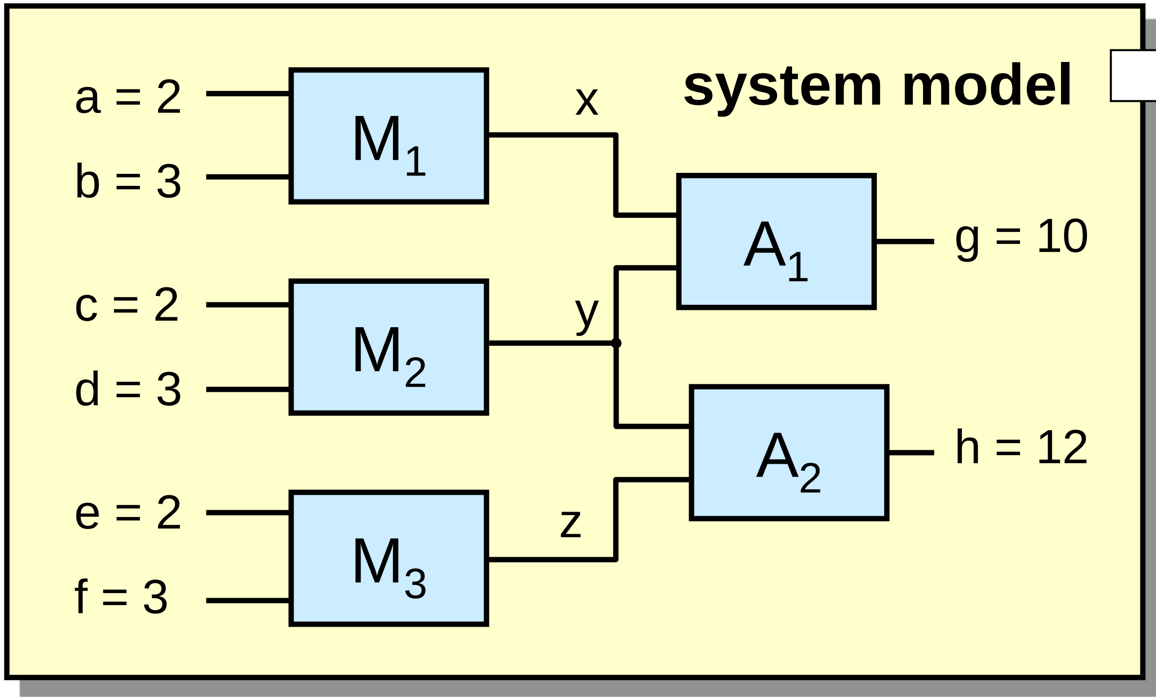


component models

- multiplier: mode=ok $\Rightarrow$ out = $in_1 * in_2$
- adder: mode=ok $\Rightarrow$ out = $in_1 + in_2$

measurements: $g = 10 \wedge h = 12$

GDE - Example



simulation

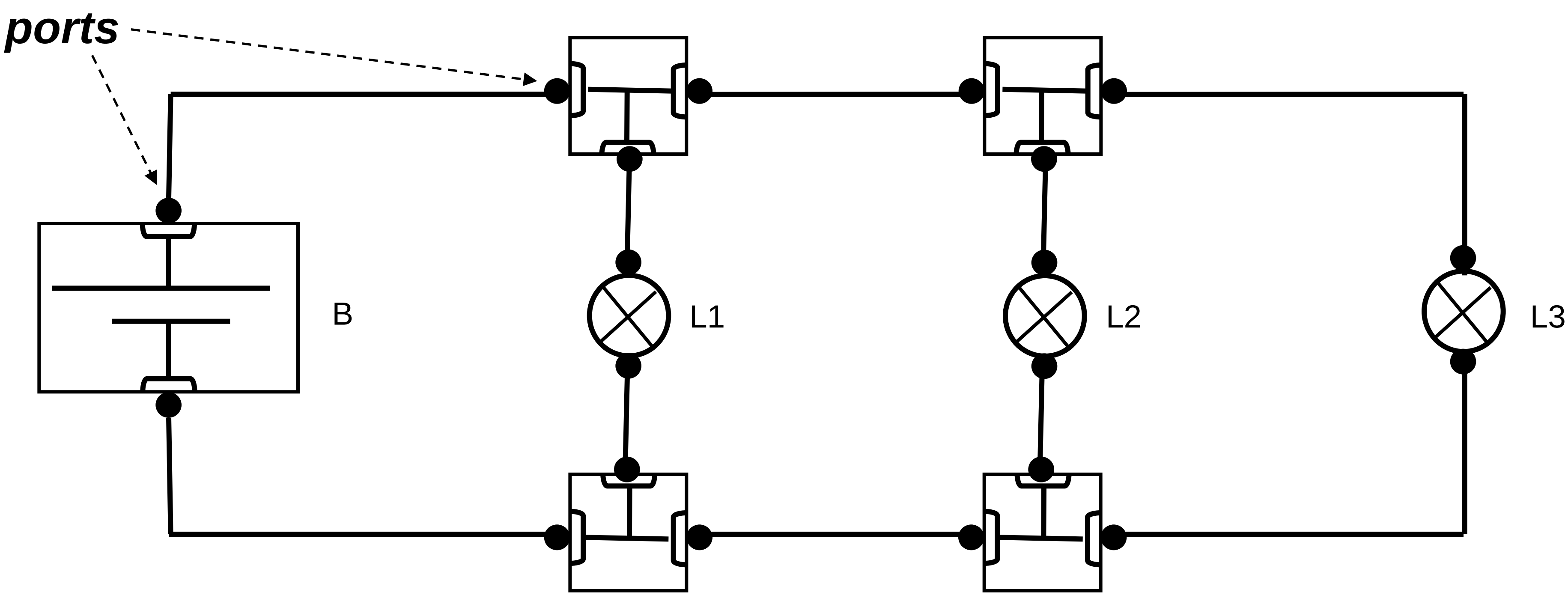
x = 6 {M1}
y = 6 {M2}
z = 6 {M3}
g = 12 {M1 M2 A1}, g =10
y = 4 {M1 A1}
h = 10 {M1 A1 A2 M3}, h = 12
y = 6 {A2 M3}

two conflicts

M1	M2	M3	A1	A2
X	X		X	
X		X	X	X

diagnoses:
single-fault M1
single-fault A1
double fault M2 M3
:

Modeling a simple electric circuit in a first shot



component types:

Battery

Lamp

Wire

Junction (3)

Model-Based Diagnosis: Base functionality

Models of electric components:

Battery:

value ranges: minus, plus ∈ { `ground`, `supply voltage` }

rules: ok ⇒ (minus = `ground`)

ok ⇒ (plus = `supply voltage`)

Wire:

value ranges: a1, a2 ∈ { `ground`, `supply voltage` }

rules: ok ∧ (a1 = `ground`) ⇒ (a2 = `ground`)

ok ∧ (a1 = `supply voltage`) ⇒ (a2 = `supply voltage`)

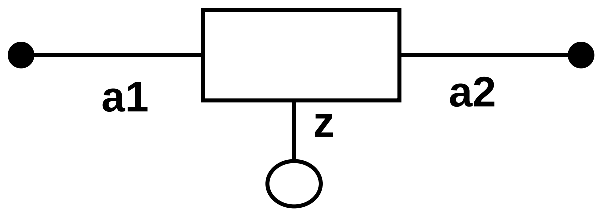
ok ∧ (a2 = `ground`) ⇒ (a1 = `ground`)

ok ∧ (a2 = `supply voltage`) ⇒ (a1 = `supply voltage`)

Model-Based Diagnosis: Base functionality

Models of electric components:

<u>Lamp</u>:



value ranges:

$a1, a2 \in \{ \texttt{ground}, \texttt{supply voltage} \}$

$z \in \{ \texttt{lit}, \texttt{dark} \}$

rules:

$ok \wedge (a1 = \texttt{supply voltage}) \wedge (a2 = \texttt{ground}) \Rightarrow (z = \texttt{lit})$

$ok \wedge (a2 = \texttt{supply voltage}) \wedge (a1 = \texttt{ground}) \Rightarrow (z = \texttt{lit})$

$ok \wedge (a1 = \texttt{supply voltage}) \wedge (a2 = \texttt{supply voltage}) \Rightarrow (z = \texttt{dark})$

$ok \wedge (a1 = \texttt{ground}) \wedge (a2 = \texttt{ground}) \Rightarrow (z = \texttt{dark})$

$ok \wedge (a1 = \texttt{ground}) \wedge (z = \texttt{lit}) \Rightarrow (a2 = \texttt{supply voltage})$

$ok \wedge (a1 = \texttt{supply voltage}) \wedge (z = \texttt{lit}) \Rightarrow (a2 = \texttt{ground})$

$ok \wedge (a1 = \texttt{ground}) \wedge (z = \texttt{dark}) \Rightarrow (a2 = \texttt{ground})$

$ok \wedge (a1 = \texttt{supply voltage}) \wedge (z = \texttt{dark}) \Rightarrow (a2 = \texttt{supply voltage})$

$ok \wedge (a2 = \texttt{ground}) \wedge (z = \texttt{lit}) \Rightarrow (a1 = \texttt{supply voltage})$

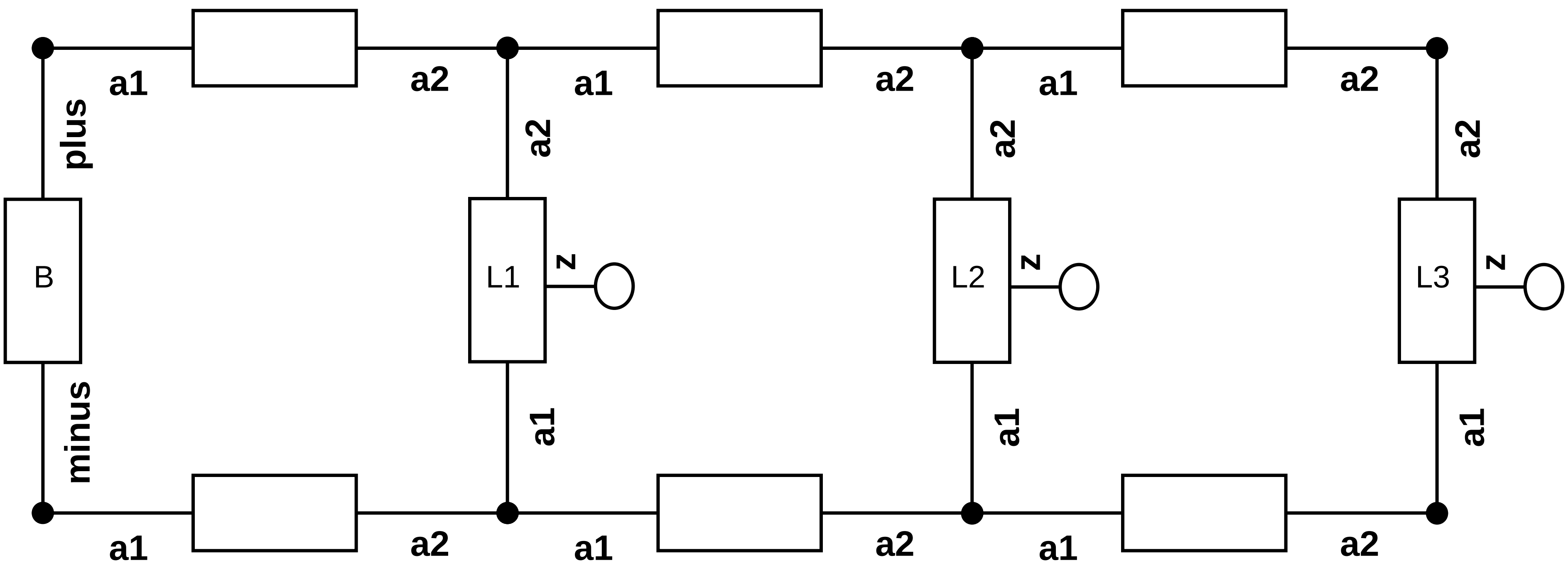
$ok \wedge (a2 = \texttt{supply voltage}) \wedge (z = \texttt{lit}) \Rightarrow (a1 = \texttt{ground})$

$ok \wedge (a2 = \texttt{ground}) \wedge (z = \texttt{dark}) \Rightarrow (a1 = \texttt{ground})$

$ok \wedge (a2 = \texttt{supply voltage}) \wedge (z = \texttt{dark}) \Rightarrow (a1 = \texttt{supply voltage})$

Model-Based Diagnosis: Base functionality

Composing the system model from the component models:



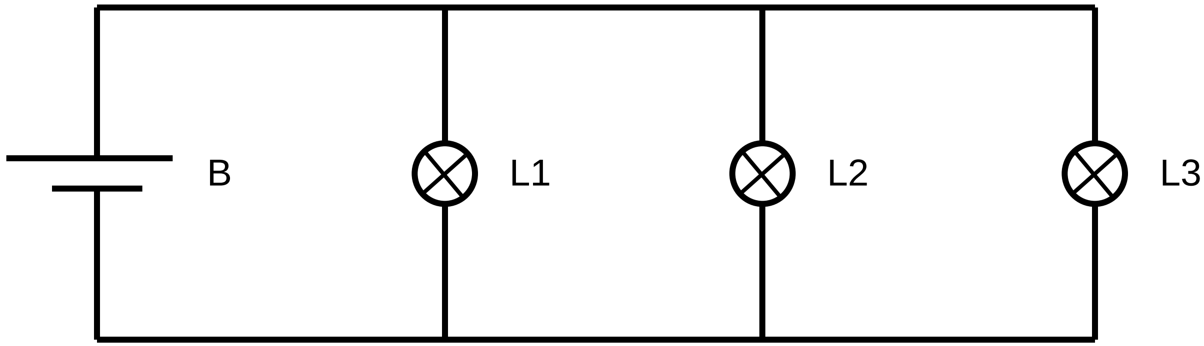
Values at connecting ports must be the same from both sides.

In case of contradiction: Conflict between the behavioural modes predicting the resp. values

Diagnoses are sets of behavioural modes not containing any conflict.

Model-Based Diagnosis: Base functionality

Example why the adder/multiplier example does not reveal all difficulties for practice:



Observation:

L1, L2 are not lit, L3 is lit

GDE diagnoses:

1. **(B ok, L1 faulty, L2 faulty, L3 ok)**
2. **(B faulty, L1 ok, L2 ok, L3 faulty)** **???**
3. **(B faulty, L1 ok, L2 ok, L3 ok)** **???**

Model-Based Diagnosis: Base functionality

Conclusion from this modeling:

There is no logic contradiction to the following diagnosis:

2. (B faulty, L1 ok, L2 ok, L3 faulty)

Reason:

L3 may be lit in fault mode even if there is no voltage difference.

Incomplete knowledge base !

Even worse:

If a behavioural rule is only evaluated when its antecedents assume actual values, then no contradiction can be found to the following diagnosis:

3. (B faulty, L1 ok, L2 ok, L3 ok)

Reason:

There is no voltage value computed anywhere in the system.

Incomplete inference ability of the problem solver !

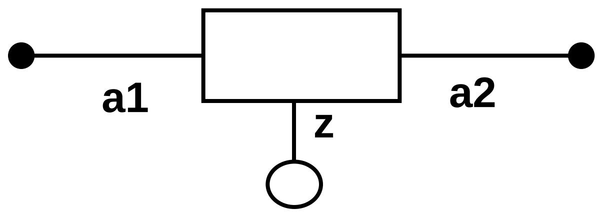
Model-Based Diagnosis: Base functionality

Additional rules for the exclusion of diagnoses 2 / 3:

Battery:

faulty ⇒ (minus = `ground`)

Lamp:



faulty ∧ (a1 = `supply voltage`) ∧ (a2 = `supply voltage`) ⇒ (z = `dark`)

faulty ∧ (a1 = `ground`) ∧ (a2 = `ground`) ⇒ (z = `dark`)

There must be models for faulty behaviour, too, in order to exclude diagnoses that are physically impossible.

Model-Based Diagnosis: Extended functionality

Base functionality:

Input:

- Setting certain control inputs
- Observing values depending on this setting

Output:

- Several diagnoses of the following kind:
  - Jeach diagnosis assigns a behavioural mode to each component: ok or a defined fault mode
  - The rules of all behavioural modes assigned agree with all set and observed values.

What does the user need ?

Input: see above

Output:

- A unique instruction how to repair which component

Model-Based Diagnosis: Extended functionality

Extended functionality:

1) Suggestion of setting certain control inputs

- Setting certain values at certain places in the system

  (such that the observations to be expected differ such that the diagnoses valid so far may be distinguished best)

2) Suggestion of observation points

- Selecting observation points

  (such that the observations to be expected differ such that the diagnoses valid so far may be distinguished best)

Test (items 1 and 2)

Requirement for the modeling:

- Definition of test points
- Definition of test values to be set at the test points
- Definition of observation points to be measured

Control actions (test points and test values)

Observations (observation points)

Modeling the components in a proper way

Behavioural modes

- modes of the component to be searched for in the diagnostic process
- Domain of definition must be finite (normall less than 10 values)

Variables

- containing values
- The variable values are used in the constraints.
- The constraints compute new values for other variables.

Ports

- containing variables to be identified at the connections to adjacent components

Distinguish internal variables from port variables !

Constraints

- set of behavioural rules connecting the variables of the same component
- Normally, a constraint is only valid under the assumption of a certain behavioural mode.

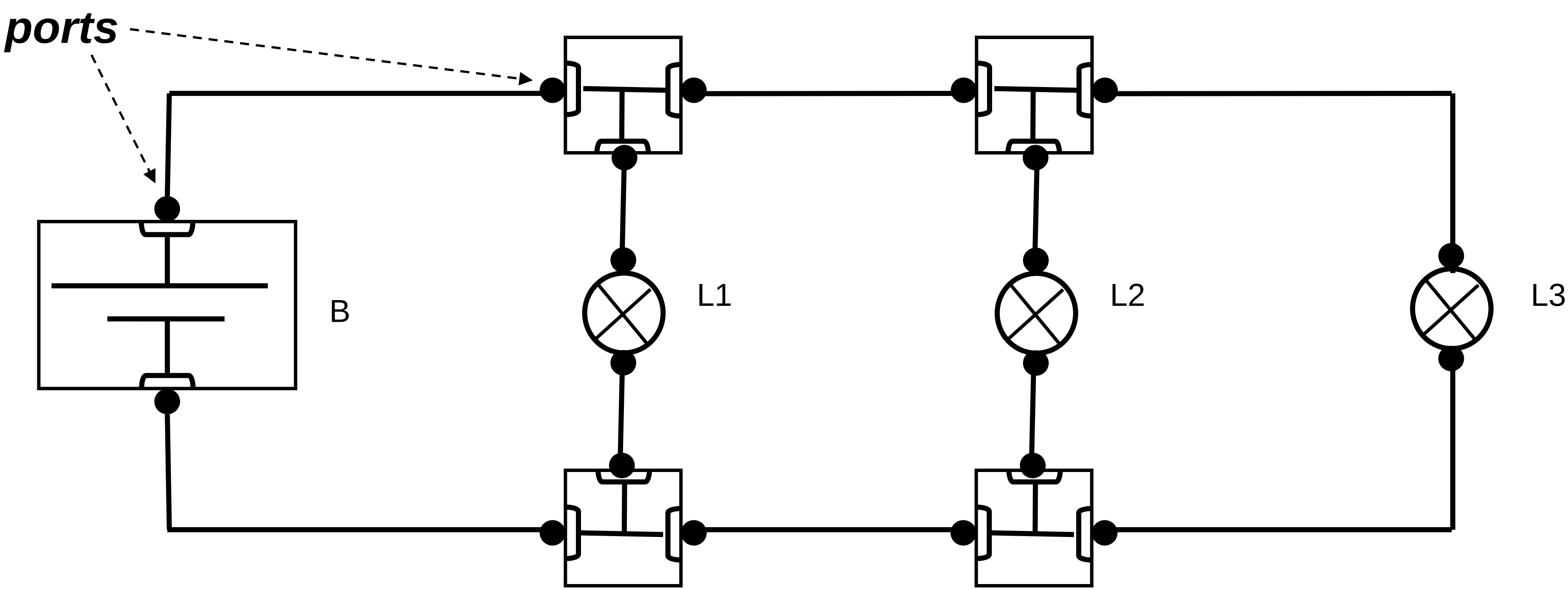
Control actions

- variables and values to be set
- measure of accessibility and the difficulty to set certain values.

Observations

- variables
- measure for accessibility

Modeling a simple electric circuit in a proper way



component types:

Battery

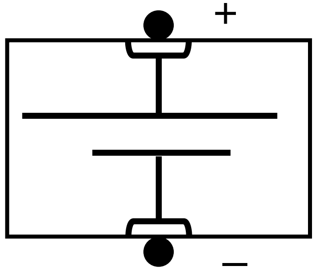
Lamp

Wire

Junction (3)

Modeling a simple electric circuit

Battery



ports: `+, -`

constraints:

cf. slides 10, 15

fault modes:

```
discharged
contact gap at +
contact gap at -
loose contact at +
loose contact at -
corroded
```

control actions:

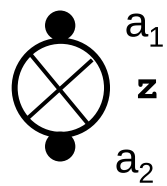
```
open connector at +
open connector at -
close connector at +
close connector at -
```

observations:

```
inspect connectors
measure voltage at +
measure voltage at -
```

Modeling a simple electric circuit

<u>**Lamp**</u>



ports: a_1, a_2

internal variables: `z`

constraints:

cf. slides 11, 15

fault modes:

```
blown
lamp is not inserted
loose contact
corroded
```

control actions:

```
remove lamp
insert lamp
```

observations:

```
inspect lamp
```

<u>**Wire**</u>

ports: a_1, a_2

constraints:

cf. slides 10

fault modes:

```
broken
shorted to ground
shorted to voltage
corroded
```

control actions:

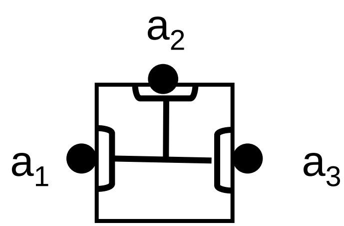
observations:

measure voltage at a_1

measure voltage at a_2

inspect wire

Modeling a simple electric circuit



Junction (3)

ports: a_1, a_2, a_3

constraints:

exercise

(related to wires)

fault modes:

contact gap at a_1
contact gap at a_2
contact gap at a_3
loose contact at a_1
loose contact at a_2
loose contact at a_3

control actions:

close contact at a_1
close contact at a_2
close contact at a_3
open contact at a_1
open contact at a_2
open contact at a_3

observations: inspect contacts