Overview

- Learning and simulations
- Research questions
  - Diagnosing learning behaviour
  - Curriculum planning
  - Explanation (incl. visualisation) *(brief)*
- Concluding remarks
- Applications and References *(brief)*

Cognitive diagnosis: *Outstanding problem in AIED*

Goal:

interpretation of the ‘problem solving behaviour’ of a learner

(e.g. correct, incorrect, incorrect in a certain way, incomplete, etc.)

That is:

construct a model of the knowledge state of a learner

In order to:

determine next step in the interaction

(e.g. Explanation / Re-mediation / Assignment / etc.)

Useful to distinguish between

- local *(w.r.t. a specific answer)*
- global *(learner behaviour over time)*

Cognitive diagnosis: *subtraction, a typical research domain*

Diagnose the errors !

$$\begin{array}{r} {}^{-1} \\ 1\,4\,3 \\ 2\,8\,- \\ \hline 1\,2\,5 \end{array}$$

(1)

$$\begin{array}{r} 1\,4\,3 \\ 2\,8\,- \\ \hline 1\,2\,5 \end{array}$$

$$\begin{array}{r} 1\,4\,8 \\ 2\,3\,- \\ \hline 1\,2\,5 \end{array}$$

(two errors !!)

(2)

$$\begin{array}{r} 5\,4 \\ 3\,8\,- \\ \hline 7\,2 \end{array}$$

(3)

$$\begin{array}{r} 9\,0\,4 \\ 7\,- \\ \hline 8\,0\,7 \end{array} \qquad \begin{array}{r} 9\,0\,4 \\ 2\,3\,7\,- \\ \hline 5\,7\,7 \end{array}$$

(4)

$$\begin{array}{r} 8\,6\,3 \\ 1\,3\,4\,- \\ \hline 7\,4\,9 \end{array} \qquad \begin{array}{r} 8\,9\,3 \\ 1\,0\,4\,- \\ \hline 8\,0\,9 \end{array}$$

Cognitive diagnosis: *Typical approaches & their problems*

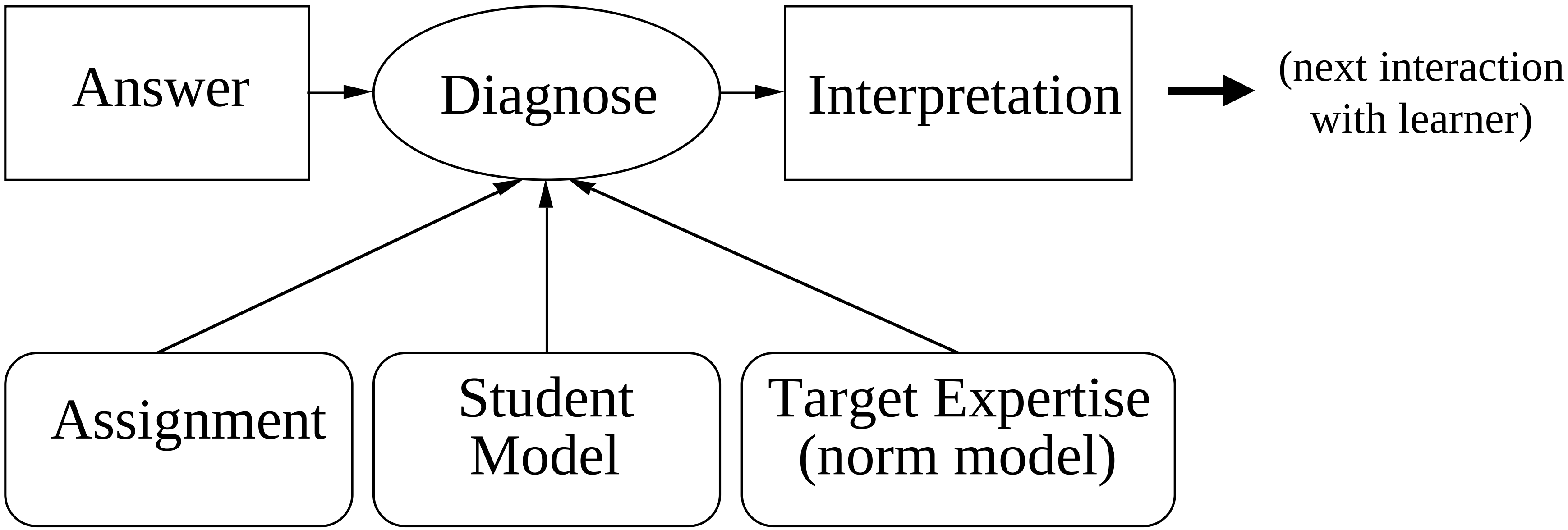
- Overlay
  - novices behave different from experts
  - no knowledge of faults

- Catalogue of Bugs / Misconceptions
  - a lot of work
  - domain dependent
  - never complete

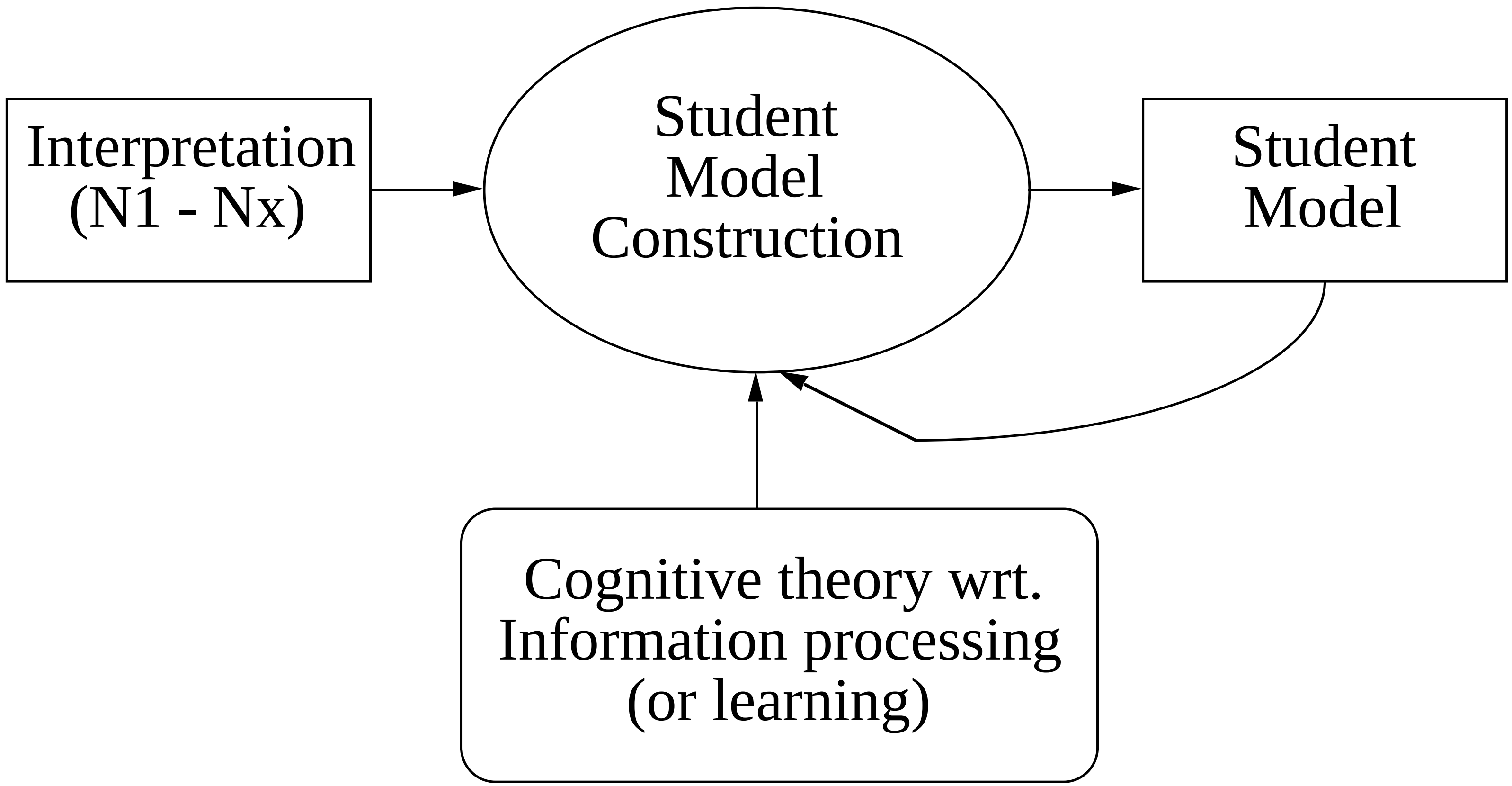
- Generative
  - requires theory of cognition/learning
  - requires domain specific pruning

- Model-Based Approach ?! (= consistency-based diagnosis)

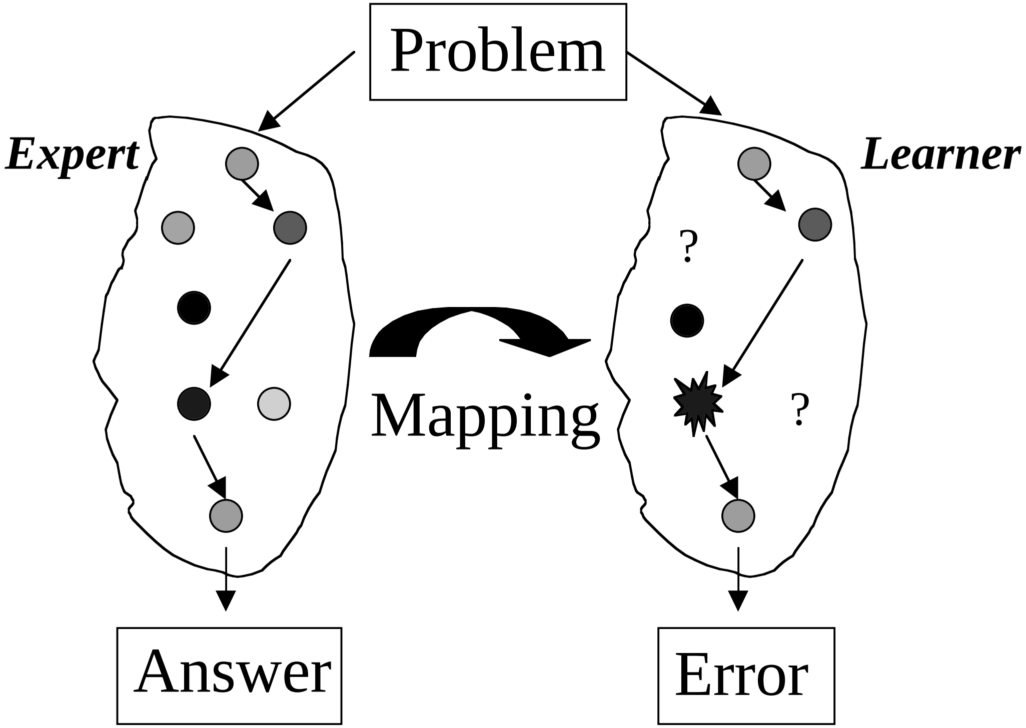
Cognitive diagnosis: *Local view*



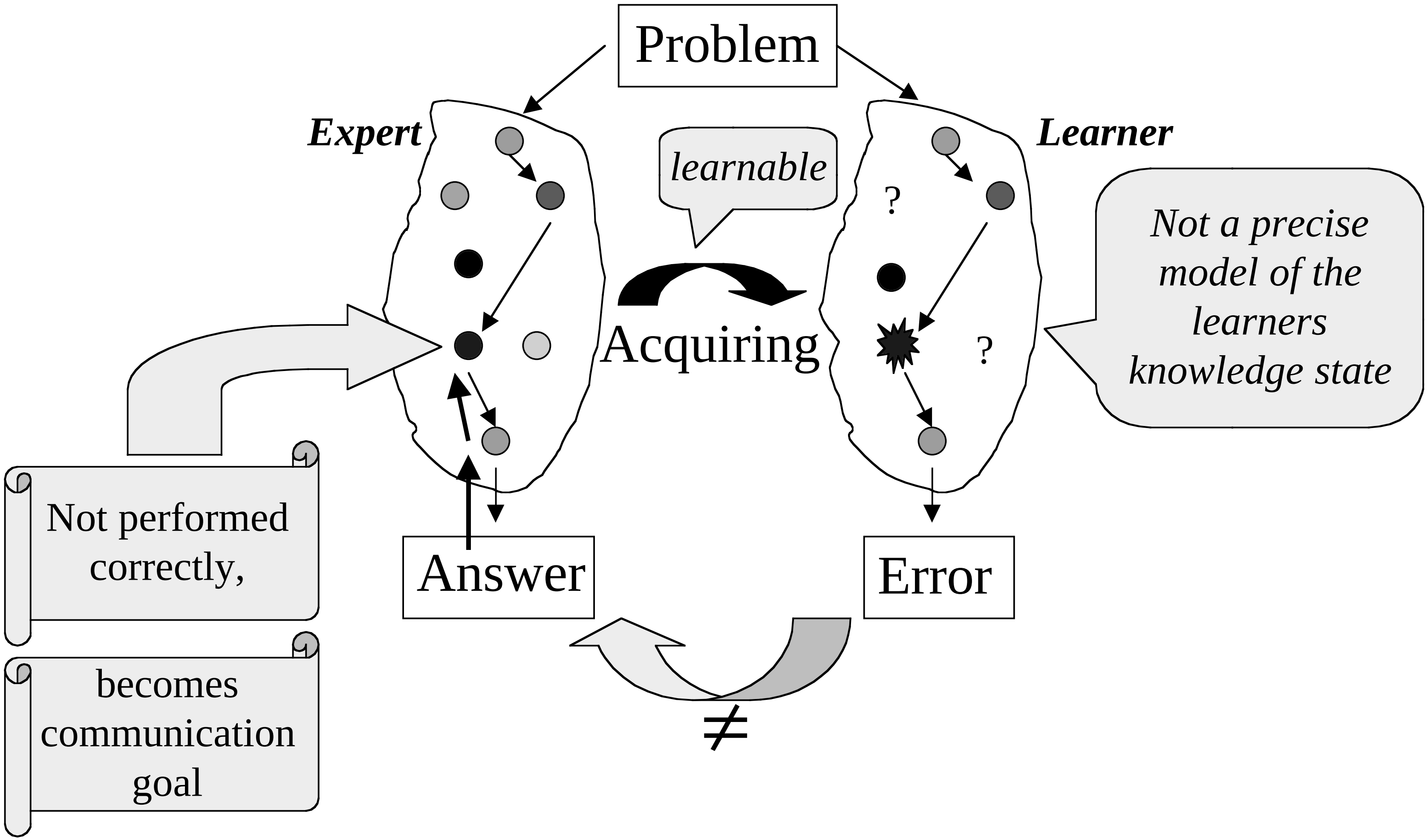
Cognitive diagnosis: *Global view*



Cognitive diagnosis: previous techniques



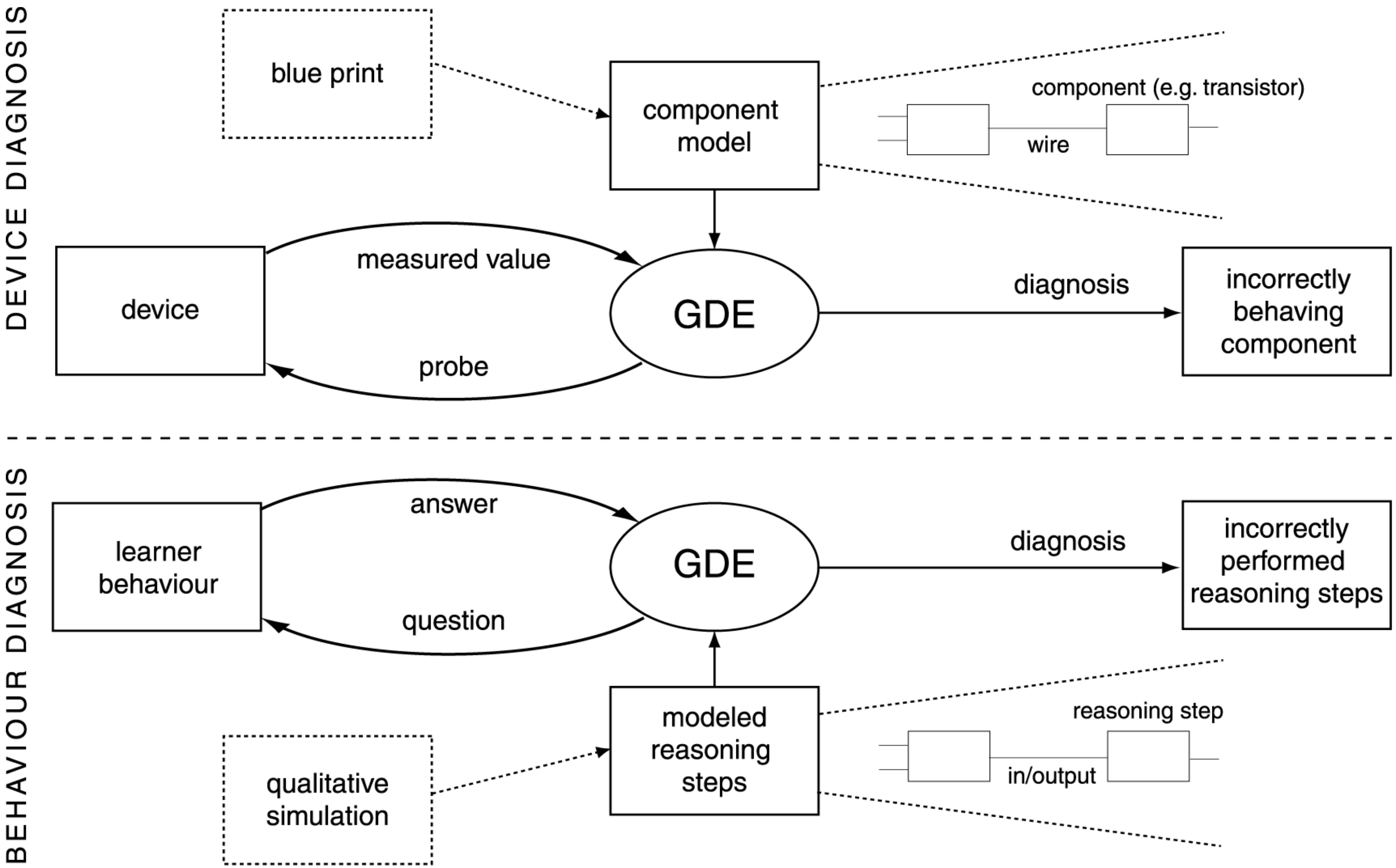
Cognitive diagnosis: consistency based



(Inspired on experiments with real teachers, see: de Koning, 1998)

GDE for Diagnosing Learner Behaviour

Basic idea



GDE for Diagnosing Learner Behaviour

What to do? (de Koning et al., 2000)

Base Model

- Cognitive validity (inference steps) (see: de Koning, 1998)
- Component-connection paradigm (Qualitative Model → GDE)

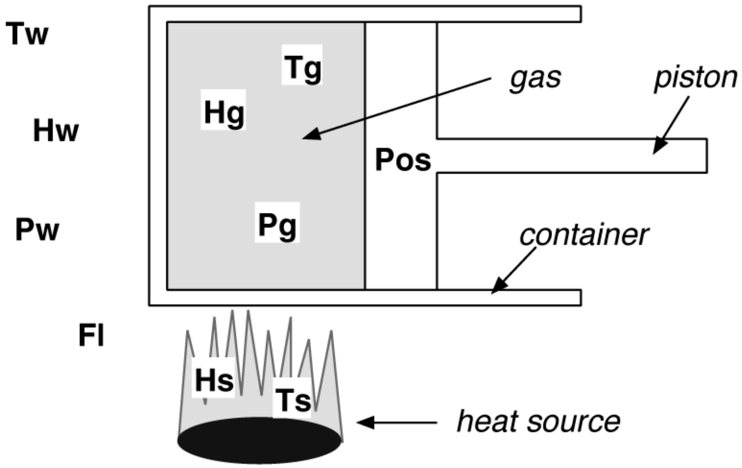
Make it work

- Diagnostic engine (→ aggregation..)
- Probe selection & Probing

Evaluate

- Diagnosis
- Approach as a whole

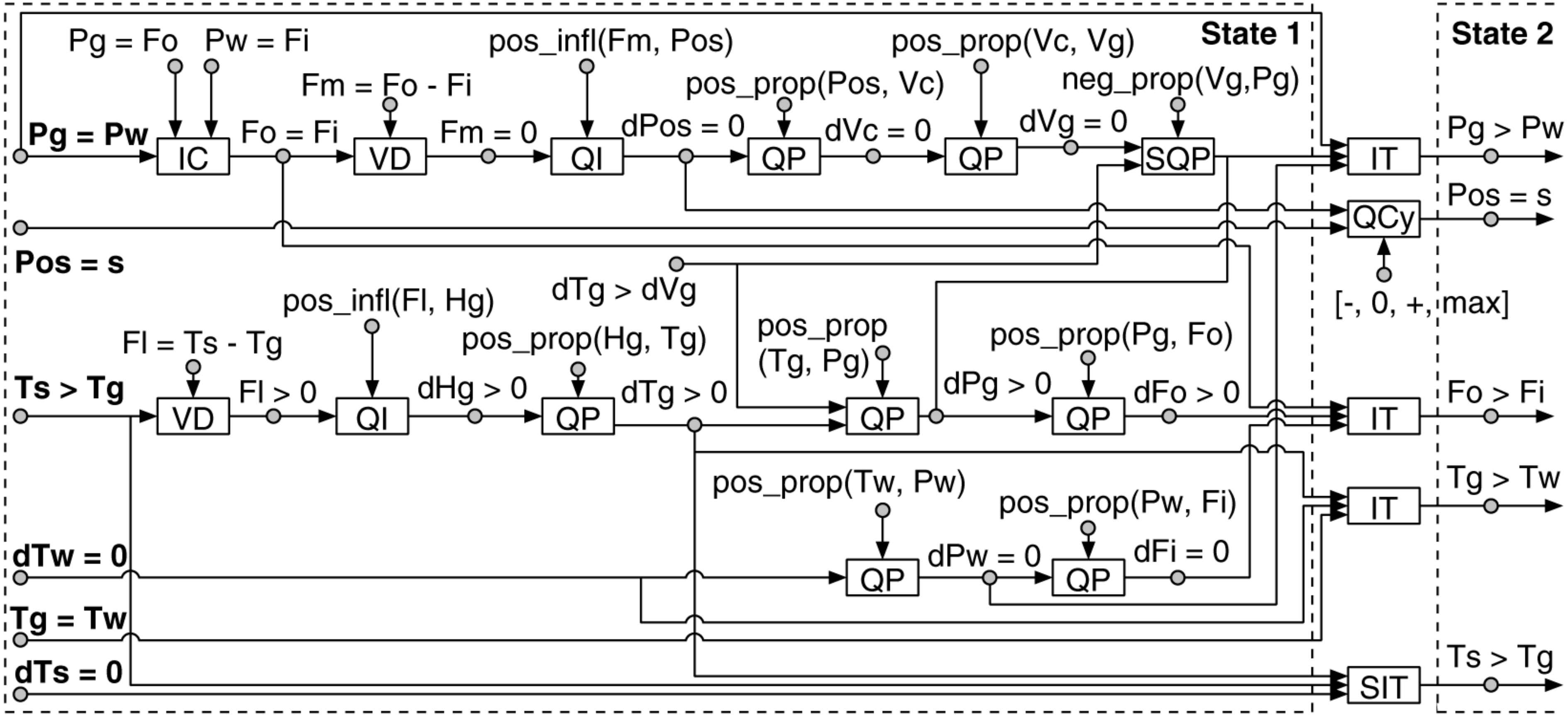
Example: The Container-Piston System



Tw	= temperature of the surrounding world
Hw	= heat of the surrounding world
Pw	= pressure of the surrounding world
Tg	= temperature of the gas
Hg	= heat of the gas
Pg	= pressure of the gas
Ts	= temperature of the heat source
Hs	= heat of the heat source
Fl	= heat flow between heat source and gas
Pos	= position of the piston

"Because the temperature of the heater is higher than the temperature of the gas, there will be a heat flow from the heater to the gas. Therefore, the temperature of the gas will no longer be equal to the temperature of the outside world, but will become higher."

The Base Model

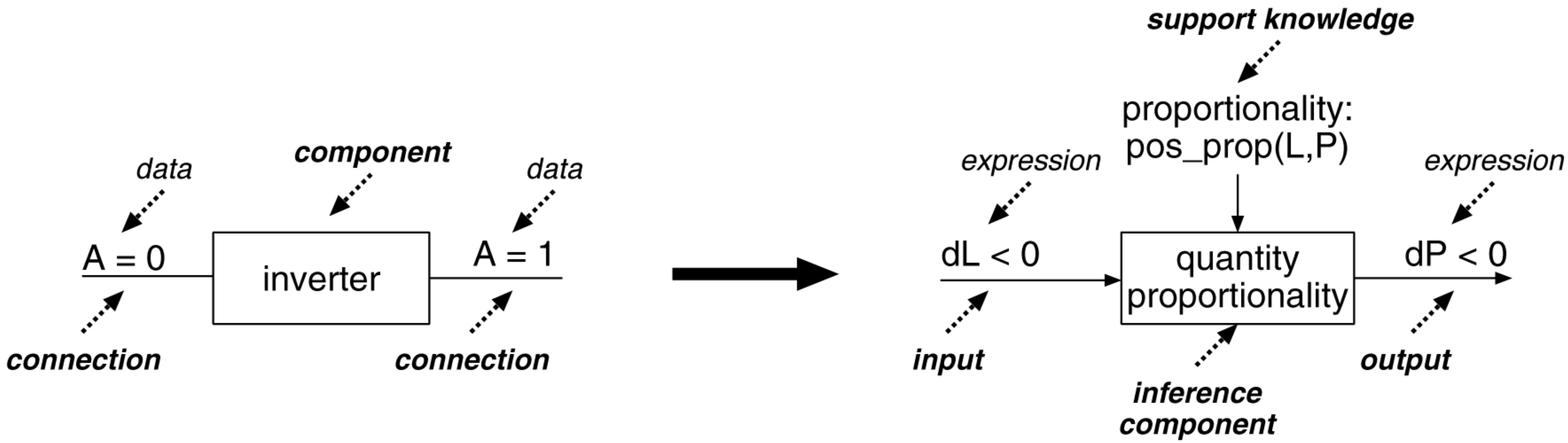


IC = *inequality correspondence*
VD = *value determination*
QI = *quantity influence*
QP = *quantity proportionality*

SQP = *submissive quantity proportionality*
IT = *inequality termination*
SIT = *submissive inequality termination*
QCy = *quantity continuity*

The Base Model *issues (1a)*

Components and Component Behaviour



MBD: component-connection model

STAR: diagnostic knowledge model (base model)

The Base Model *issues (1b)*

Components and Component Behaviour

type: ***Quantity Influence***

ports:

<u>In</u> = quantity value, <u>Sup</u> = influence, <u>Out</u> = quantity derivative

example:

'There is a [positive] flow, so the volume decreases'

($Fl > 0$ & $neg\_infl(Fl,V) \rightarrow \partial V < 0$)

component description (behaviour rules):

<u>Forward propagation:</u> **In** & **Sup** → **Out**

IF **In** = [A = >/=/< = 0] & **Sub** = [*pos_infl*(A,B)] THEN **Out** = [∂B = +/0/-]

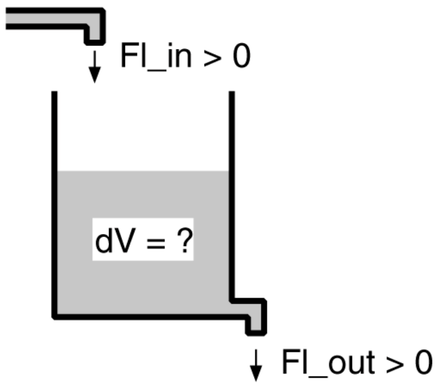
IF **In** = [A = >/=/< = 0] & **Sub** = [*neg_infl*(A,B)] THEN **Out** = [∂B = -/0/+]

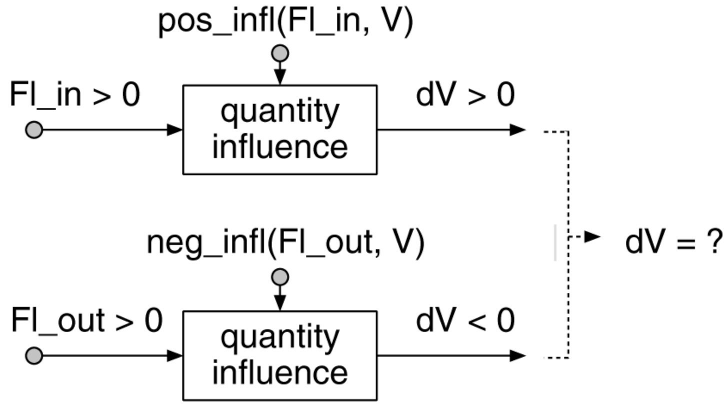
<u>Backward propagation:</u> **Out** & **Sub** → **In**

In ≠ 0 & **Out** ≠ 0 → **Sub**

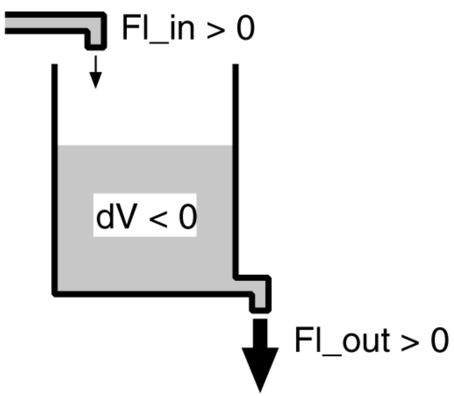
The Base Model *issues (2)*

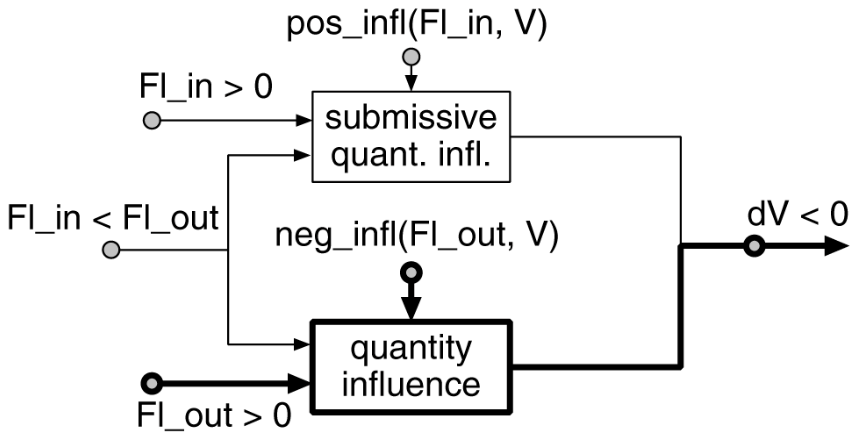
Multiple influences / proportionality's / terminations
Have <u>context</u> <u>dependent</u> behaviours…





Solution: *submissive components (e.g. submissive influence)*





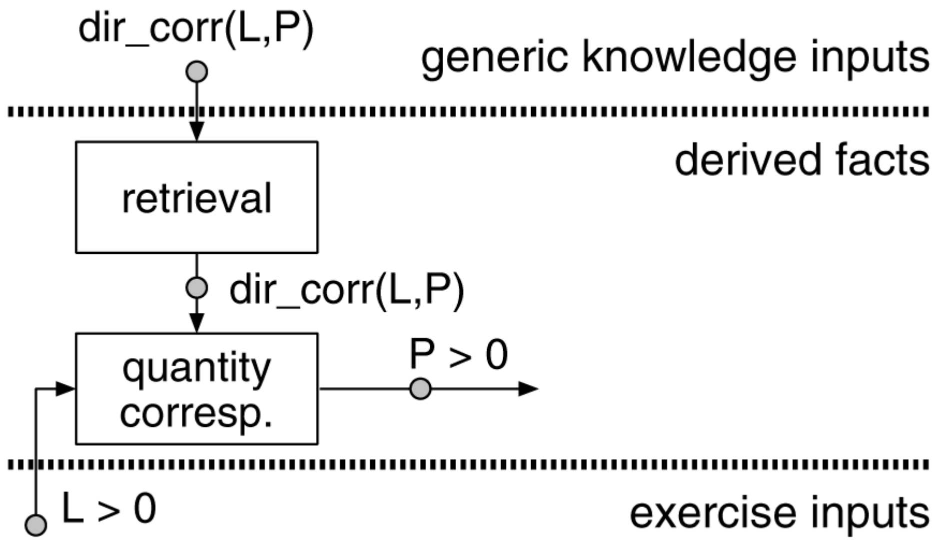
The Base Model *issues (3)*

Only components can become a diagnosis

How to distinguish between

- knowing what dependencies exist and apply
- how to reason with them (and other input / outputs)

Solution: *introduction of <u>retrieval</u> components*



GDE for Diagnosing Learner Behaviour

First try… It didn't work

Too many single faults…

- qualitative calculus (weak: ambiguous solutions)
- too few connections (fewer constraints)
- missing backwards propagation rule (a minor problem)

Solution…

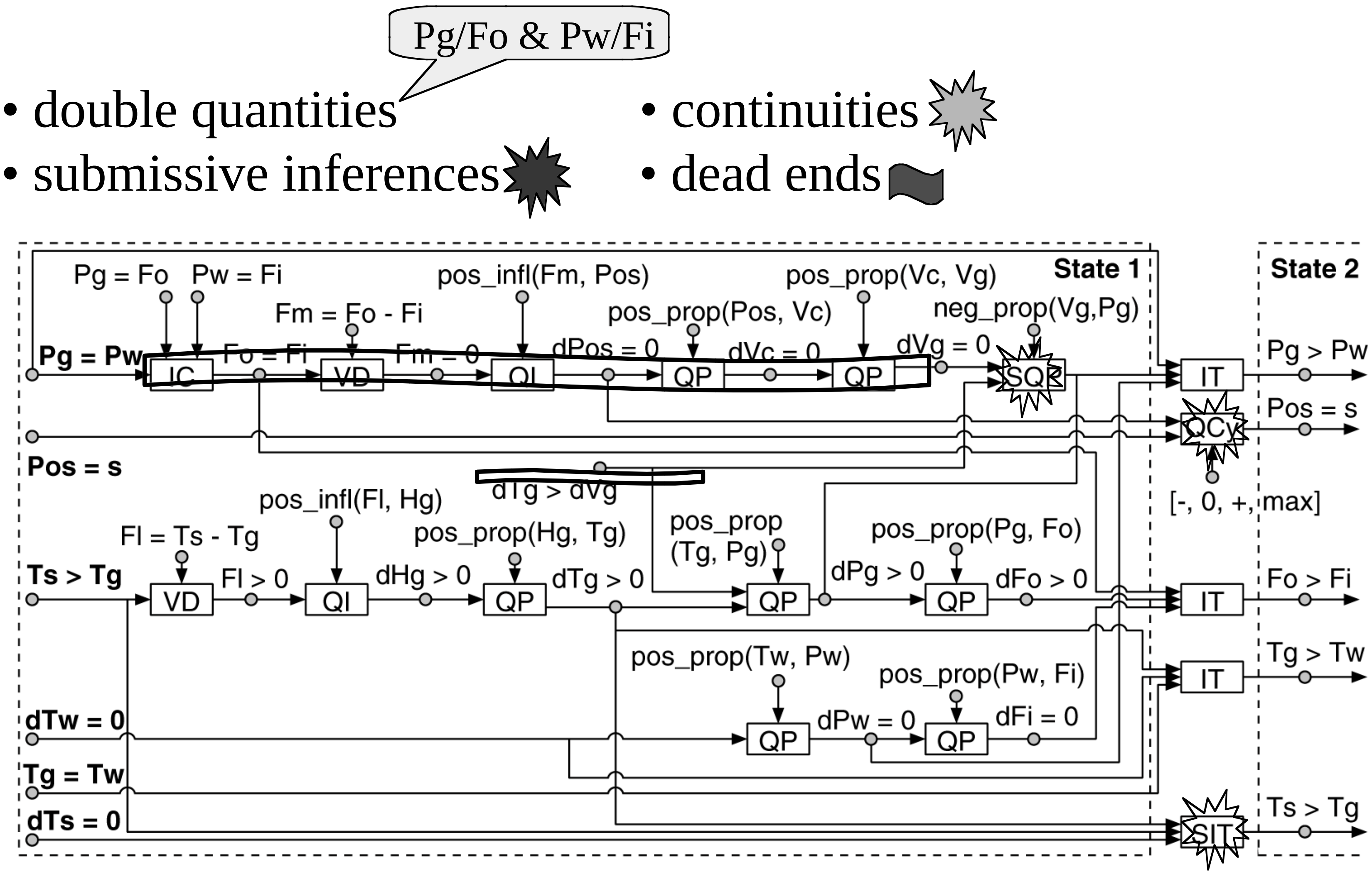
Use hierarchy of models, but …

no hierarchy information available…

➔ therefore: exploit component types

Hiding of Inessential Details

- double quantities
- submissive inferences
- continuities
- dead ends



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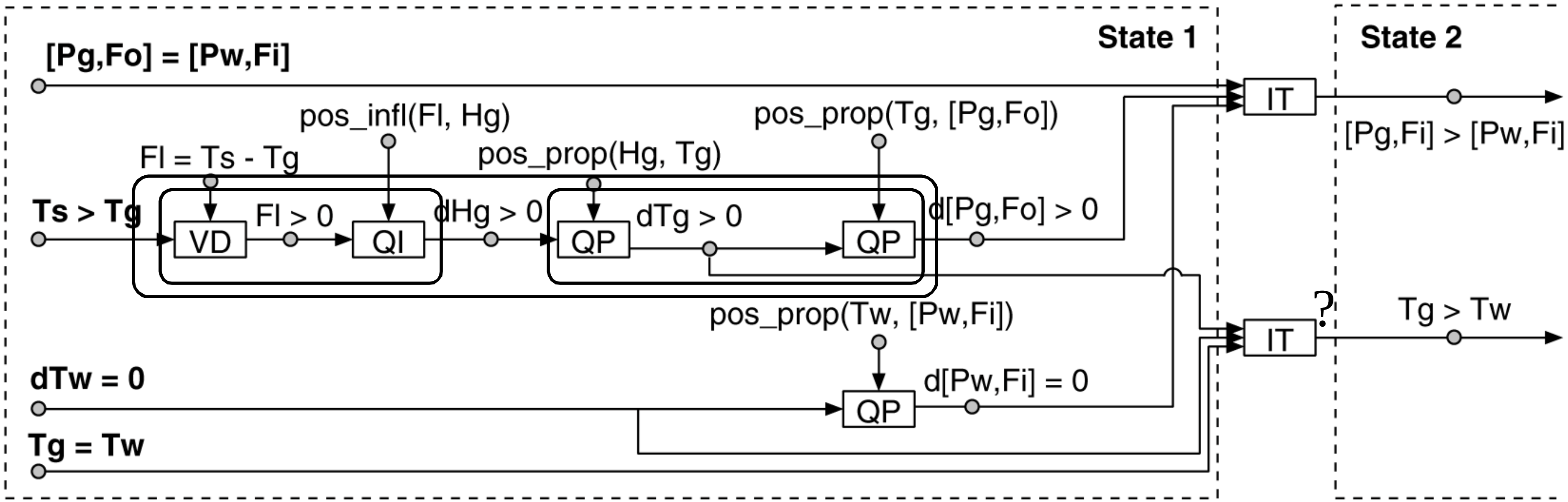
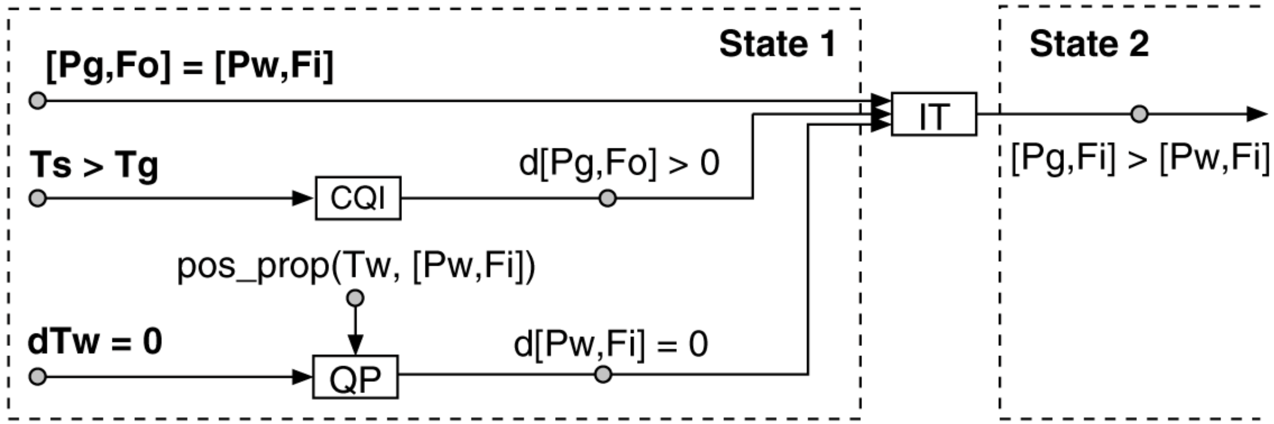
Chunking

- transitive chunking
- pred. key component chunking
- succ. key component chunking

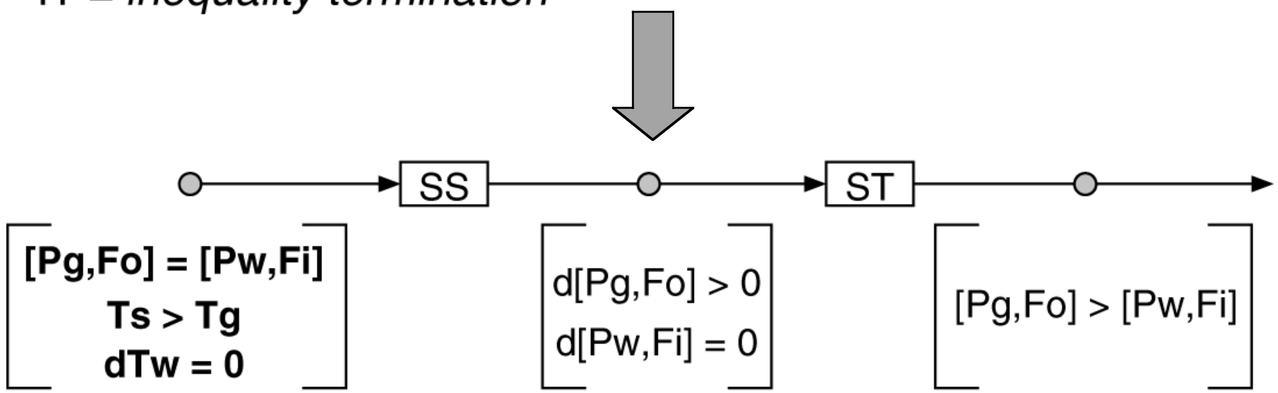


VD = *value determination* QP = *quantity proportionality*
QI = *quantity influence* IT = *inequality termination*

Grouping



QP = *quantity proportionality* CQI = *combined quantity influence*
IT = *inequality termination*



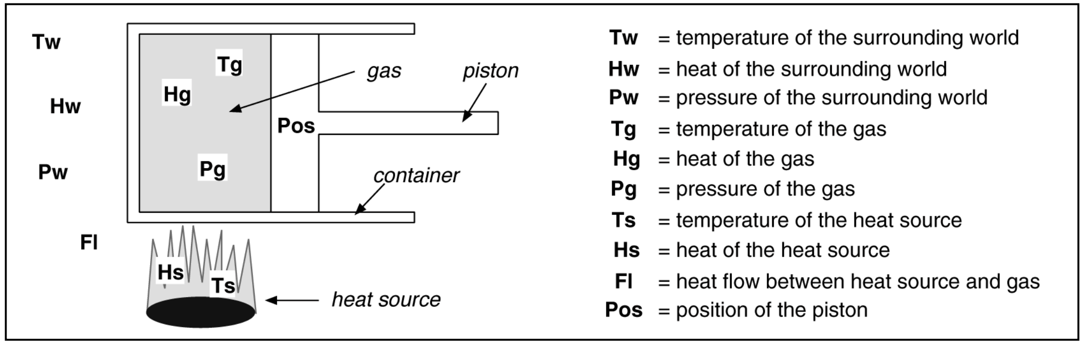
SS = *state specification* ST = *state transition*

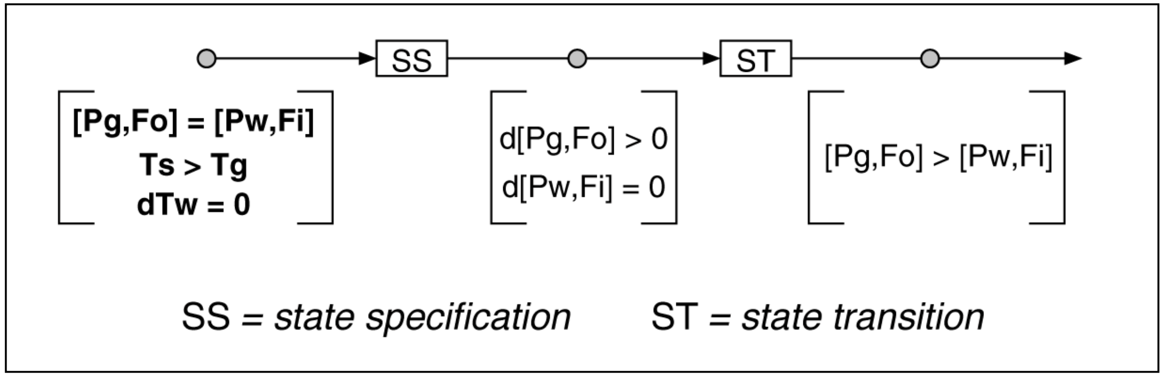
Container-piston example: Results

Number of inference components after different aggregation techniques

technique used	**nr. of components**
(base model)	824
hiding	403
chunking	220
grouping	16

An Example Diagnosis (1) *(General question / Probe 1)*





Probe 1.

Teacher: The pressure of the gas is initially equal to the pressure of the outside world (Pg = Pw). What do you think about this pressure ratio in the next behavioural state?

a. Pg < Pw
b. Pg = Pw
c. Pg > Pw

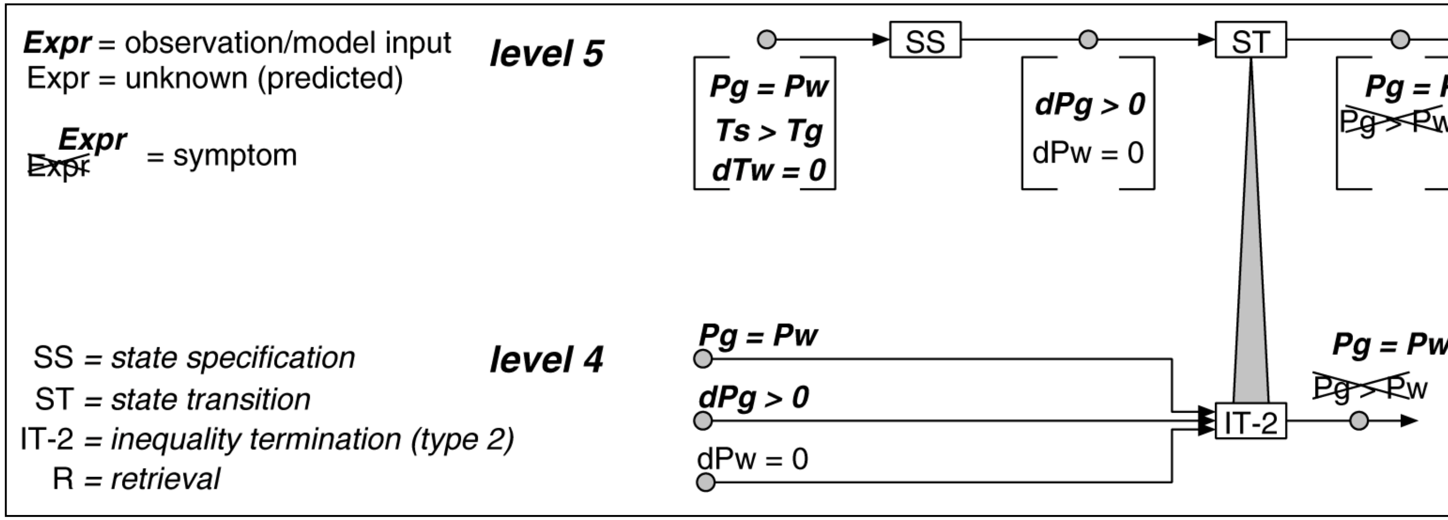
Learner: b. Pg = Pw *(NB: incorrect answer)*

An Example Diagnosis (2) *(probe 2)*

- Two expressions can be measured: ∂Pg > 0 or ∂Pw = 0. *(Suppose we ask the first one.)*

Teacher: Is the pressure of the gas initially:
a. increasing
b. steady
c. decreasing
Learner: a. increasing. *(NB: correct answer)*

- Diagnosis: Single fault diagnosis ST
- Decompose: ST (but, empty conflict set at next level)



An Example Diagnosis (3) *(probe 3)*

• The only resulting expression to ask for is ∂Pw = 0. (input for ST)

Teacher: Is the pressure of the world initially:

a. increasing

b. steady

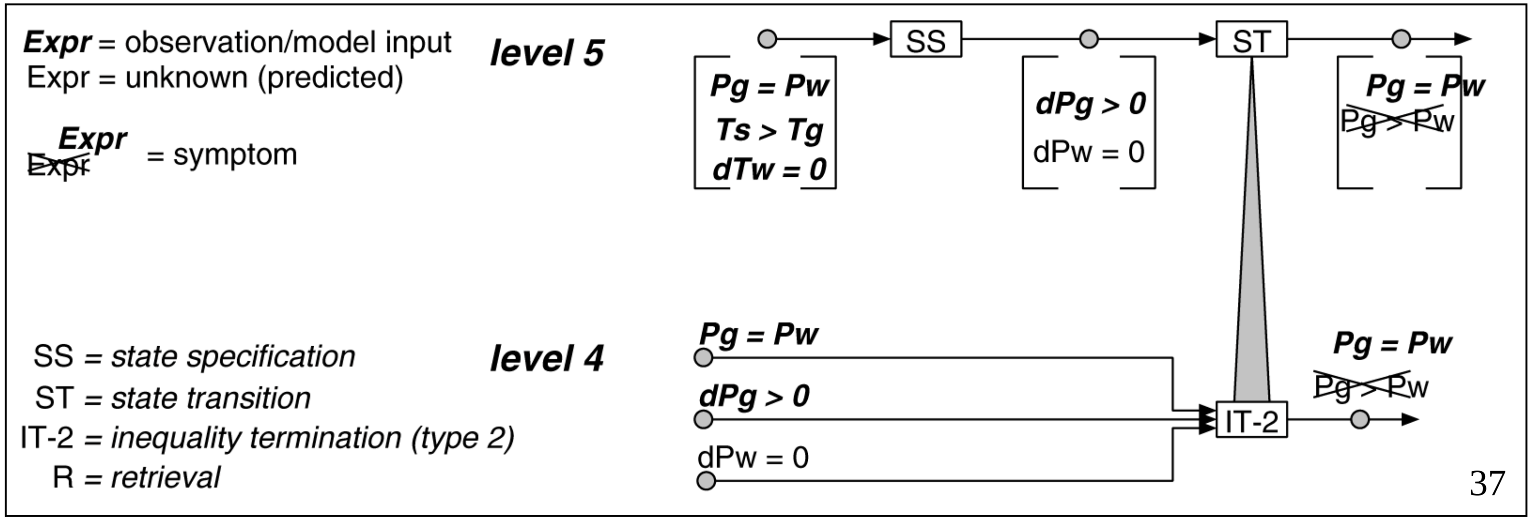
c. decreasing

Learner: b. steady. *(NB: correct answer)*

• Diagnosis: Single fault diagnosis ST

• Decompose: ST

• Diagnosis: Single fault diagnosis IT-2 (= diagnosed fault)



An Example Diagnosis (4) *(probe 2b)*

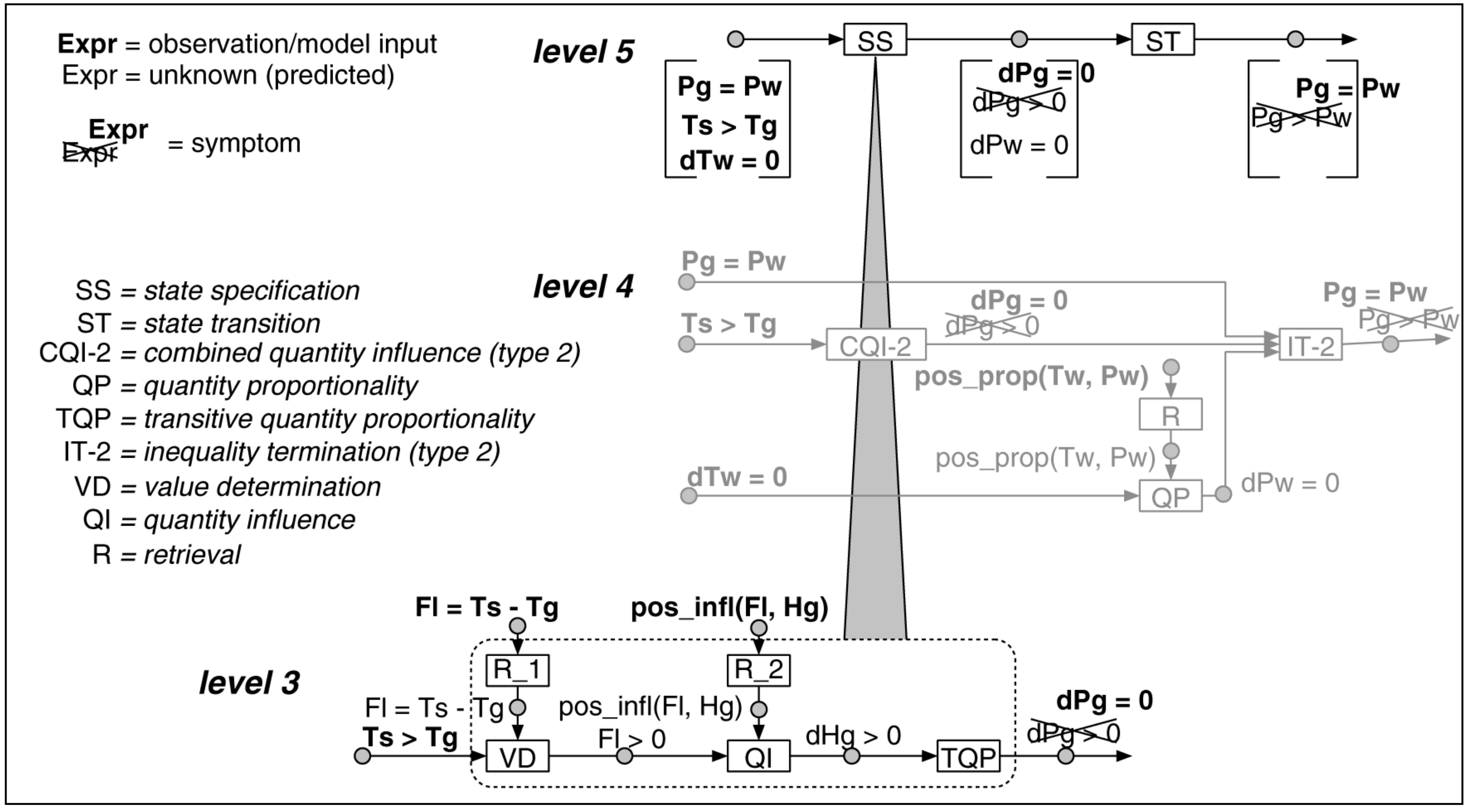
• Two expressions can be measured: ∂Pg > 0 or ∂Pw = 0. *(Suppose we ask the first one.)*

Teacher: Is the pressure of the gas initially: a. increasing b. steady c. decreasing

Learner: a. steady. *(NB: incorrect answer)* *(different answer)*

• Diagnosis: Single fault diagnosis SS
• Decompose: SS

• Diagnosis: Single fault diagnosis CQI-2
• Decompose CQI-2
Result: 5 single-fault candidates
[R1], [R2], [VD], [QI], and [TQP]



An Example Diagnosis (5) *(probe 3b)*

- Five components can be tested: [R1], [R2], [VD], [QI], or [TQP]
- Probe selection:
  - probabilities: 1.43 for [R1] and [R2]; 2.0 for [TQP]; 1.0 for [VD] and [QI]
  - best measurement Fl > 0 because: | (1.43 +1) - (1.43 + 1 + 2) | = 2 *(best split)*

<u>Teacher</u>: What is the direction of the heat flow between source and gas?

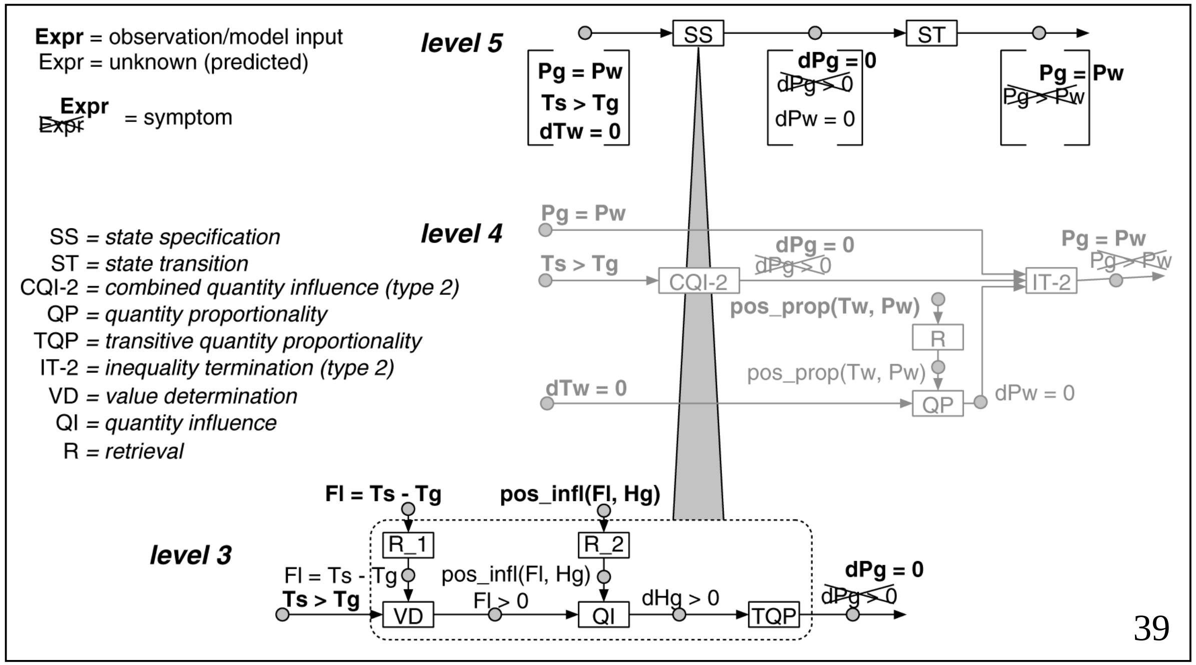
a. from source to gas

b. from gas to source

c. there is no heat flow between source and gas

<u>Learner</u>: a. from source to gas. *(NB: correct answer)*

- Diagnosis: [R2], [QI], and [TQP]



An Example Diagnosis (6) *(probe 4b)*

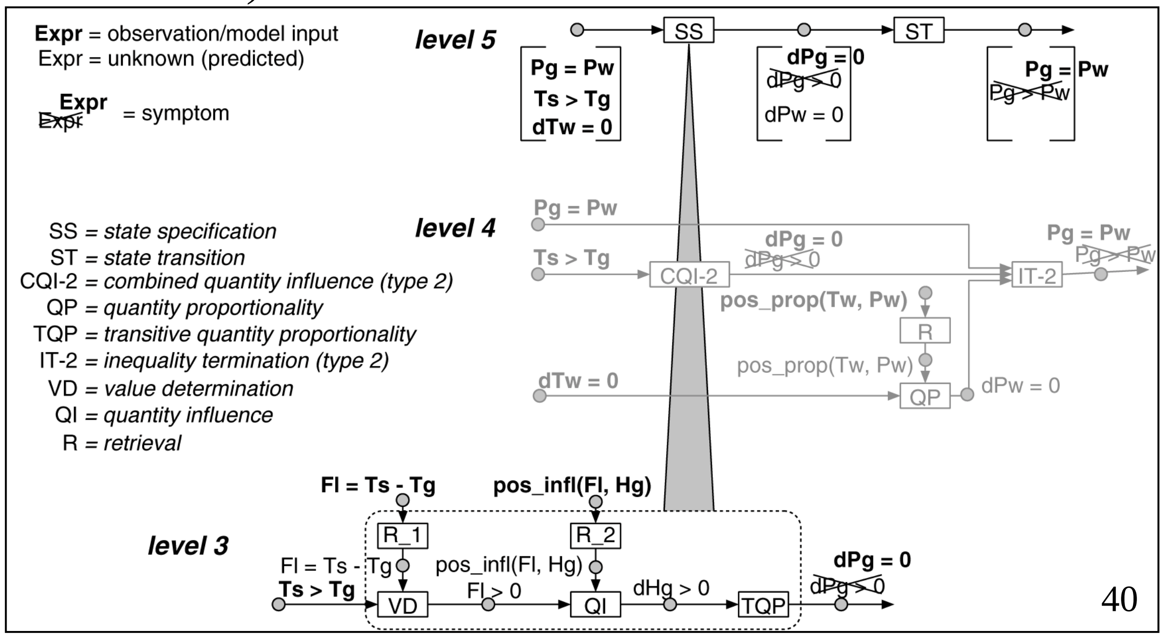
- Three components can be tested: [R2], [QI], or [TQP]
- Probe selection:
  - probabilities: 1.43 for [R2]; 2.0 for [TQP]; 1.0 for [QI]
  - measure points: *pos_infl*(Fl,Hg) ➔ | 1.43 - (1 + 2) | = 1.57
    Hg > 0 ➔ | (1.43 +1) - 2 | = 0.43 *(best split)*

<u>Teacher</u>: Is the heat of the gas initially:

a. increasing
b. steady
c. decreasing

<u>Learner</u>: a. increasing. *(NB: correct answer)*

- Diagnosis: single fault [TQP]
- Decompose: [TQP]
- Diagnosis:
  4 single faults/candidates:
  [R3], [QP1], [R4] and [QP2]



An Example Diagnosis (7) *(probe 5b)*

- Four components can be tested: [R3], [QP1], [R4] and [QP2]
- Probe selection:
  - probabilities: 1.43 for [R3] and [R4]; 1.0 for [QP1] and [QP2]
  - best measurement ∂Tg > 0 because | (1.43 +1) - (1.43 +1) | = 0 *(best split)*

  Teacher: Is the temperature of the gas initially:

  a. increasing

  b. steady

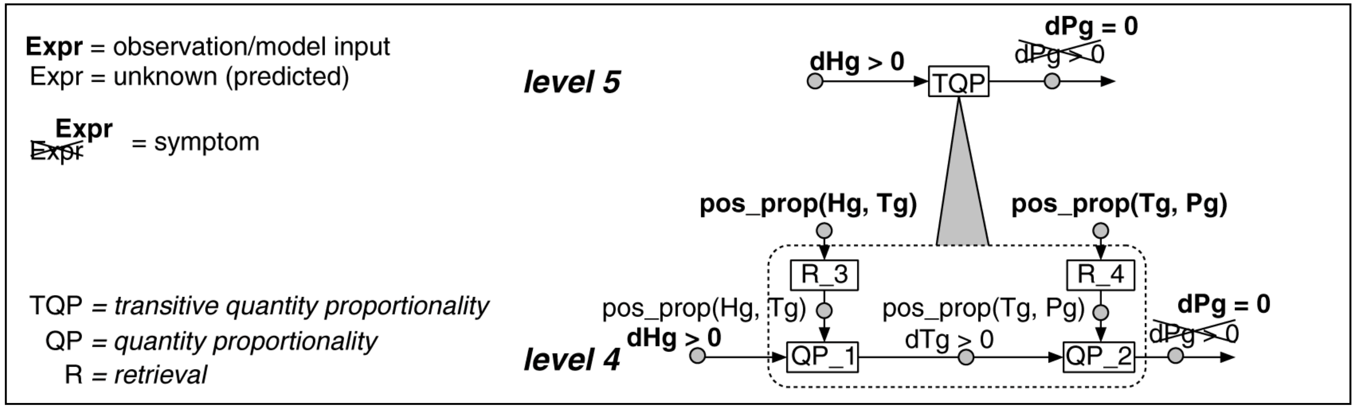
  c. decreasing

  Learner: a. increasing. *(NB: correct answer)*

- Diagnosis:

  2 single faults/candidates:

  [R4] and [QP2]



An Example Diagnosis (8) *(probe 6b)*

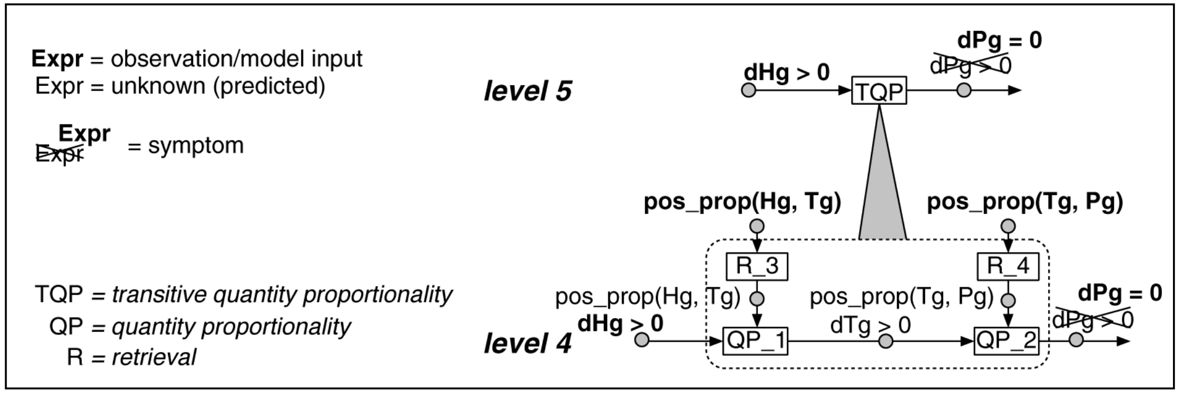
- Two components can be tested: [R4] and [QP2]
- Probe selection:
  - probabilities: 1.43 for [R4]; 1.0 [QP2]
  - only one possible probe point *pos_prop*(Tg, Hg)

<u>Teacher</u>: What is the relation between the temperature and the pressure of the gas in the current state?
a. if the temperature increases, then the pressure increases;
b. if the temperature increases, then the pressure decreases;
c. if the temperature increases, then this does not affect the pressure.

Learner: a. if the temperature increases, then the pressure increases. *(NB: correct answer)*

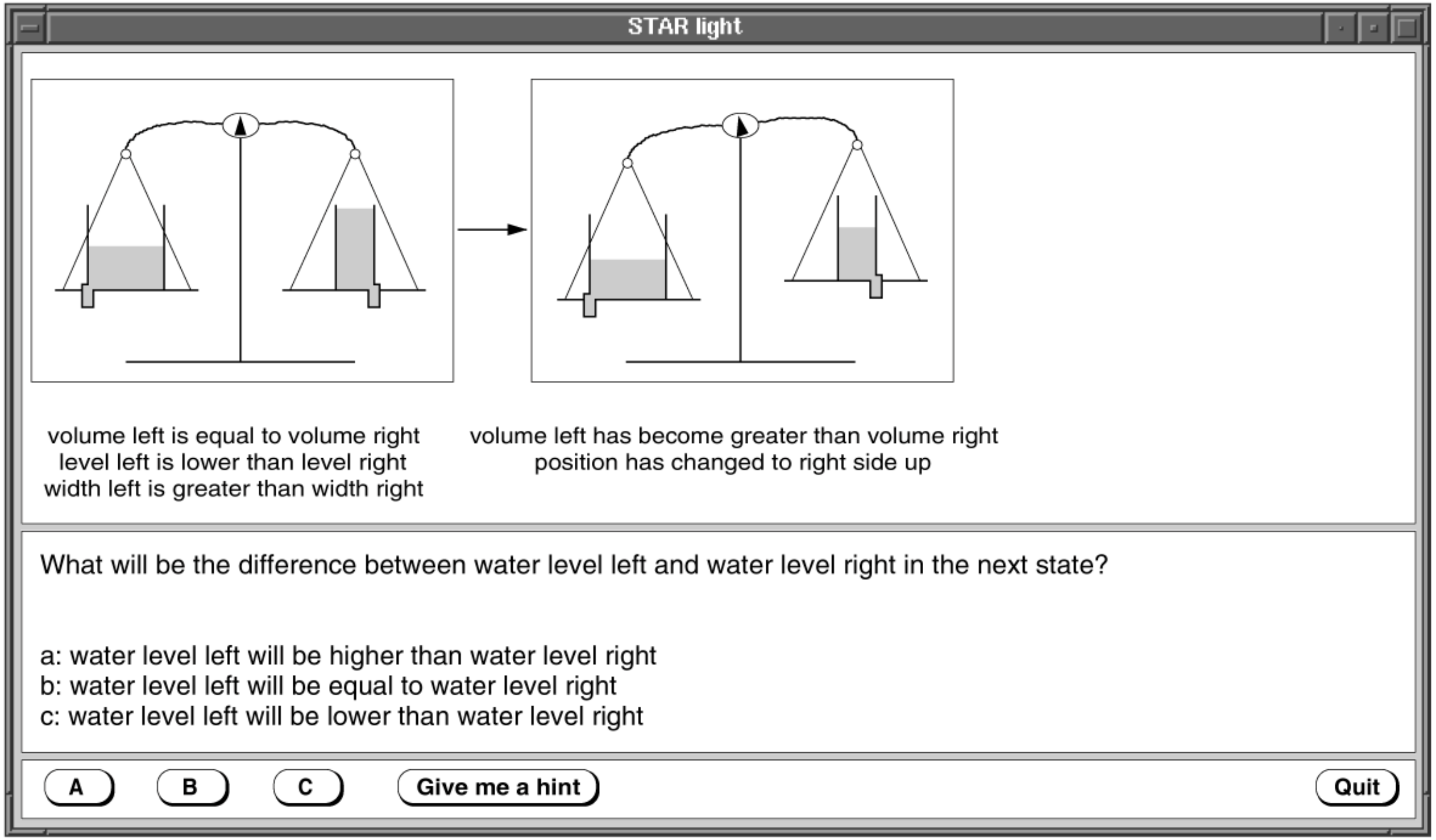
- Diagnosis: single fault [QP2]

(<u>meaning</u>: the learner does know the relation between temperature and pressure, but did not apply it here.)



GDE for Diagnosing Learner Behaviour

Evaluation with learners



On each side of the balance sits a container partially filled with water. The containers are equal in weight when empty, and have an equally sized outlet in the bottom. Through this outlet, the water flows out of the container, thereby decreasing the weight on that side of the balance. The flow rate of the two contained liquids can be different, corresponding to the pressure at the bottom. As a consequence, the balance moves to new positions, but the final state is always an equilibrium.

GDE for Diagnosing Learner Behaviour

Evaluation with learners

- 9 subjects: 4 ‘novices’ and 5 ‘experts’
- 4 exercises per subject (about 30 minutes)
- 707 questions answered
- 30 diagnostic sessions
- average number of probes: less than 3

- often triggers self-repair
- explanation insufficient for novices

Main results:
- automatic generation of hierarchical articulate simulation models
- successful application of model-based diagnosis
- domain independent