Troubleshooting with Simultaneous Models

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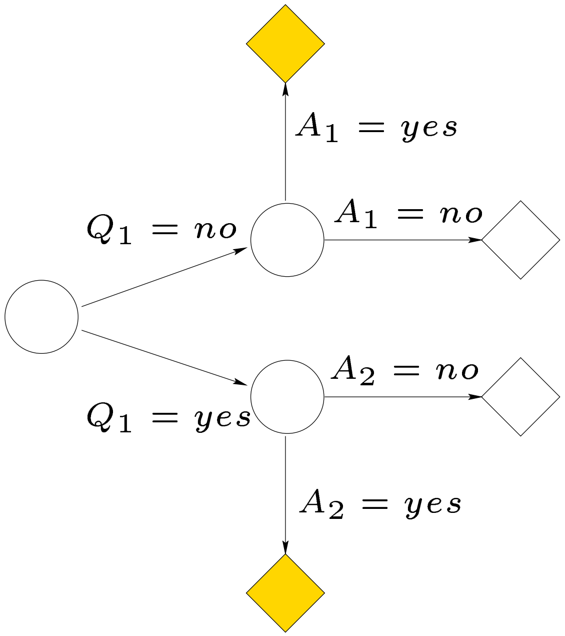
- Example: simplified light print problem.
- Troubleshooting strategy, expected cost of repair (ECR).
- NP-hardness, suboptimal strategies.
- Simultaneous models.
- SACSO models joined together.
- A troubleshooting procedure.
- The supermodel.

Trouble: a light page came out of your printer.

Troubleshooter: recommends steps to solve the trouble.

Actions and questions	*cost*
A_1: `Remove, shake and reseat toner`	5
A_2: `Try another toner`	15
A_3: `Cycle power`	1
Q_1: `Is the printer configuration page printed light?`	2

Causes of light print	$P(C_i)$
C_1: `Toner low`	0.4
C_2: `Defective toner`	0.3
C_3: `Corrupted dataflow`	0.2
C_4: `Wrong driver setting`	0.1



Strategy	Expected Cost of Repair (ECR) of Strategy		
$Q_1 \begin{cases} A_1 \\ A_2 \end{cases}$	$p(Q_1 = no, A_1 = yes)$	$\cdot$	$(c_{Q_1} + c_{A_1} + 0)$
	$+\ p(Q_1 = no, A_1 = no)$	$\cdot$	$(c_{Q_1} + c_{A_1} + c_{CS})$
	$+\ p(Q_1 = yes, A_2 = yes)$	$\cdot$	$(c_{Q_1} + c_{A_2} + 0)$
	$+\ p(Q_1 = yes, A_2 = no)$	$\cdot$	$(c_{Q_1} + c_{A_2} + c_{CS})$

Goal: find a strategy $\mathbf{s}^\star$ such that

$$\mathbf{s}^\star \quad = \quad \arg\min_{\mathbf{s}} ECR(\mathbf{s})$$

Polynomial problem (S. Srinivas, 1995)

(1a) every action solves just one fault (perfect actions),

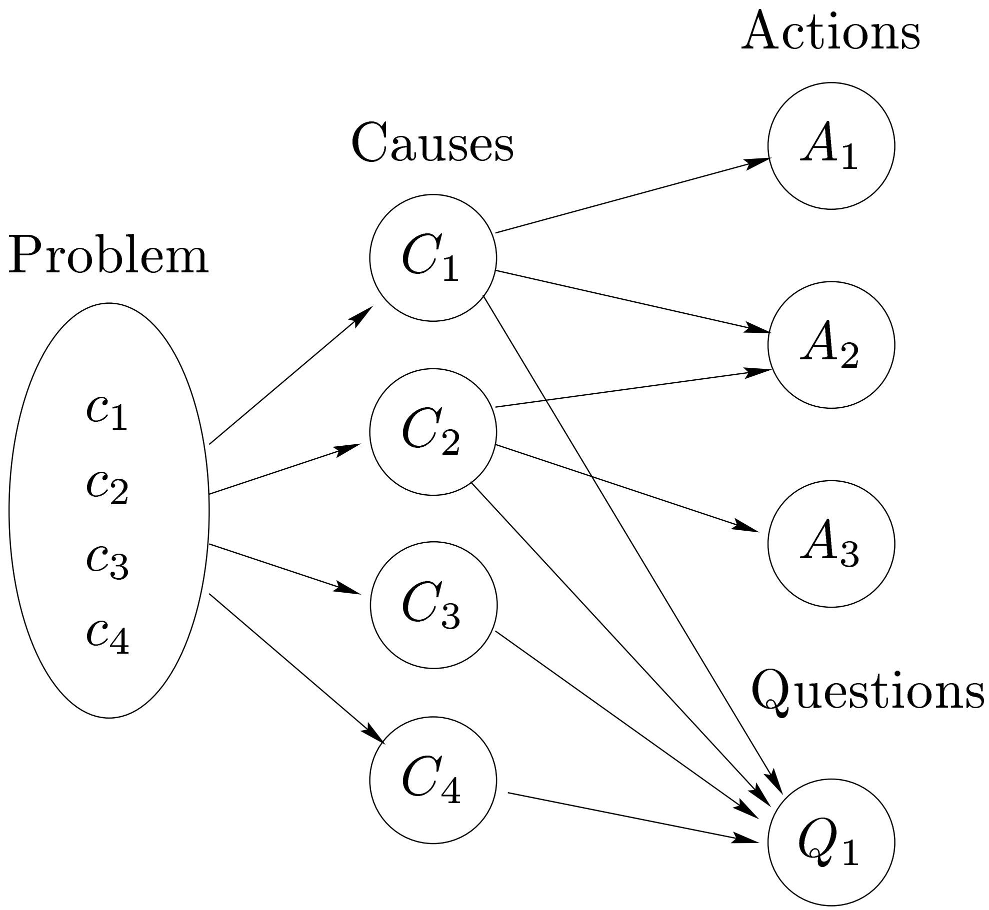
(2) all actions are pairwise conditionally independent, and

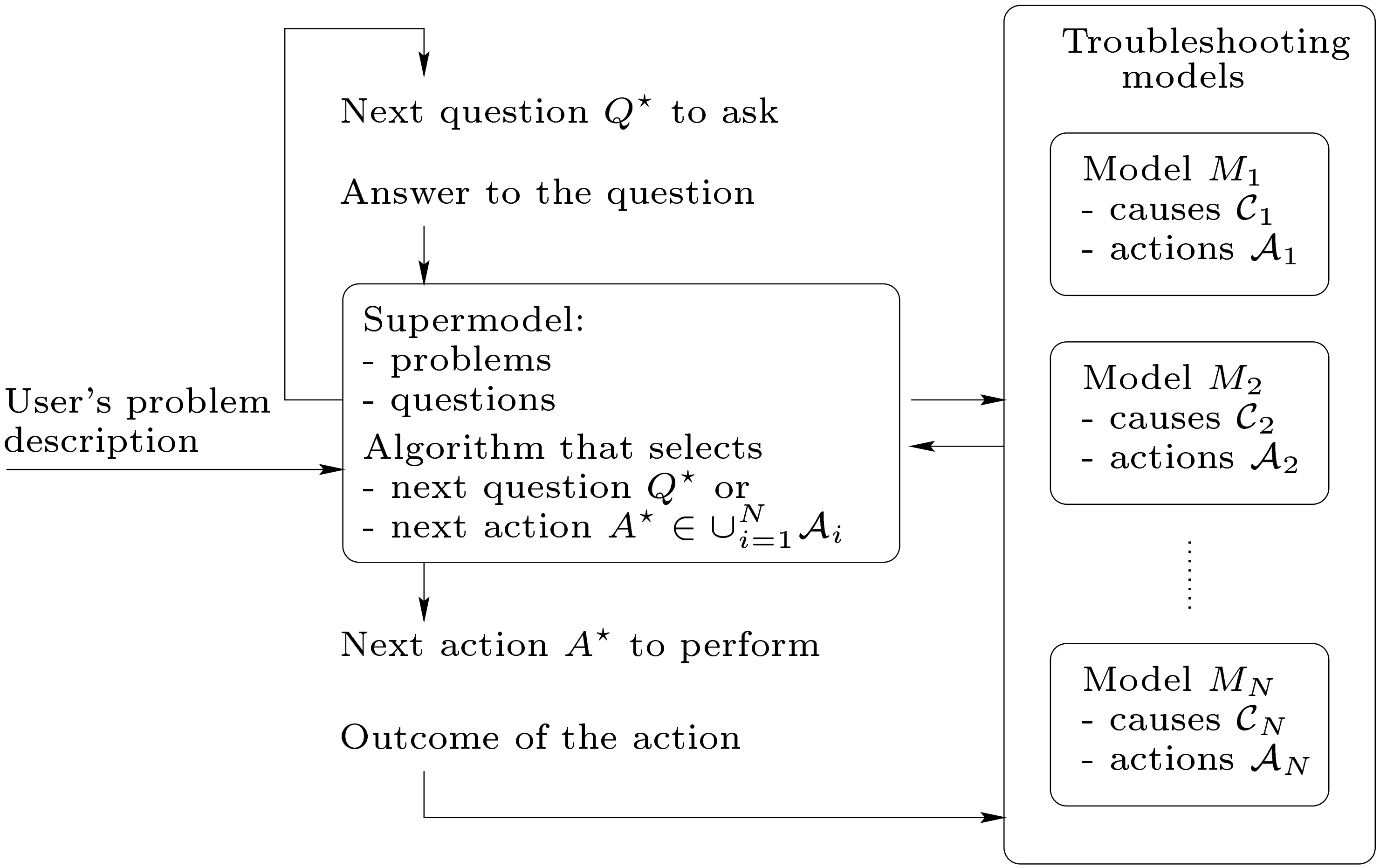
(3) single fault assumption

NP-hard problem (M. Vomlelová, 2000):

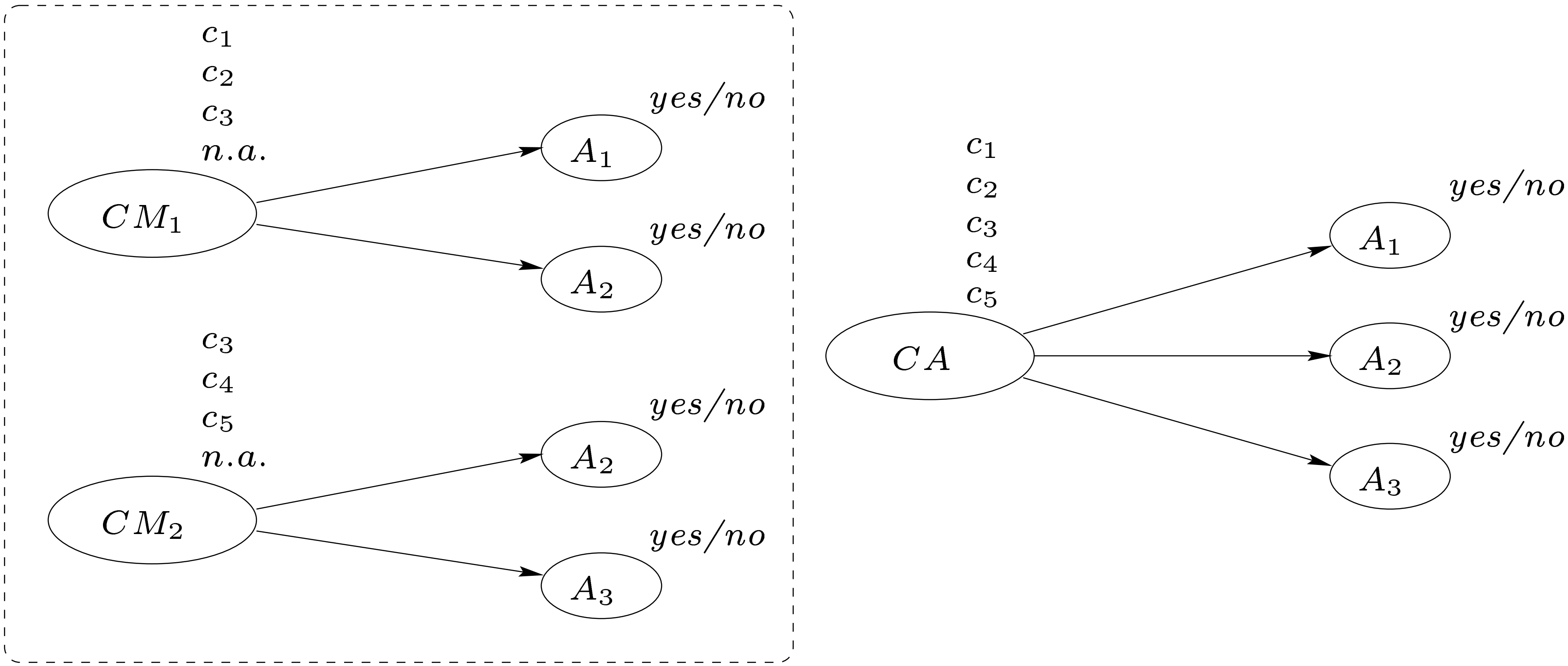
(1b) some actions solve more than one fault

Suboptimal strategies - the SACSO approach
(C. Skaanning, F. V. Jensen, and U. Kjærulff, 2000)


Actions
Causes
Problem
A_1
C_1
A_2
c_1
c_2
c_3
c_4
C_2
A_3
C_3
Questions
C_4
Q_1



Troubleshooting models
Next question $Q^\star$ to ask
Answer to the question
Model M_1
- causes $\mathcal{C}_1$
- actions $\mathcal{A}_1$
Supermodel:
- problems
- questions
Algorithm that selects
- next question $Q^\star$ or
- next action $A^\star \in \cup_{i=1}^{N} \mathcal{A}_i$
User's problem description
Model M_2
- causes $\mathcal{C}_2$
- actions $\mathcal{A}_2$
Next action $A^\star$ to perform
Outcome of the action
Model M_N
- causes $\mathcal{C}_N$
- actions $\mathcal{A}_N$


c_1
c_2
c_3
$n.a.$
CM_1
A_1
yes/no
A_2
yes/no
c_3
c_4
c_5
$n.a.$
CM_2
A_2
yes/no
A_3
yes/no
c_1
c_2
c_3
c_4
c_5
CA
A_1
yes/no
A_2
yes/no
A_3
yes/no

1. Initiate h, $\mathcal{A}(h) := \mathcal{A}$, and $P(CA = c), c \in \mathcal{C}$.
2. For each action $A \in \mathcal{A}(h)$ compute

$$P(A = yes \mid h) \quad := \quad \sum_{c \in pa(A)} P(A = yes \mid CA = c) \cdot P(CA = c \mid h)$$

$$\mathit{eff}(A \mid h) \quad := \quad \frac{P(A = yes \mid h)}{cost(A)} \quad .$$

3. Perform action $A^\star := \arg\max_{A \in \mathcal{A}(h)} \mathit{eff}(A \mid h)$.
4. If $A^\star$ solves the problem then quit
   otherwise set $e := \{A^\star = no\}$ and continue with step 5.
5. For each $c \in pa(A^\star)$ compute potential

$$f(c, e \mid h) \quad := \quad P(e \mid CA = c) \cdot P(CA = c \mid h) \quad .$$

6. For each $c \in \mathcal{C} \setminus pa(A^\star)$ set $f(c, e \mid h) := P(CA = c \mid h)$.

7. Compute the normalization constant

$$P(e \mid h) \quad := \quad \sum_{c \in \mathcal{C}} f(c, e \mid h) \ .$$

8. Normalize, i.e., for each $c \in \mathcal{C}$

$$P(CA = c \mid e, h) \quad := \quad \frac{f(c, e \mid h)}{P(e)} \ .$$

Update $h := h \cup \{A^\star = no\}$ and $\mathcal{A}(h) := \mathcal{A}(h) \setminus A^\star$.
If $\mathcal{A}(h) = \emptyset$ then quit.
Otherwise, go to step 2.

The procedure can be performed using the original SACSO models.

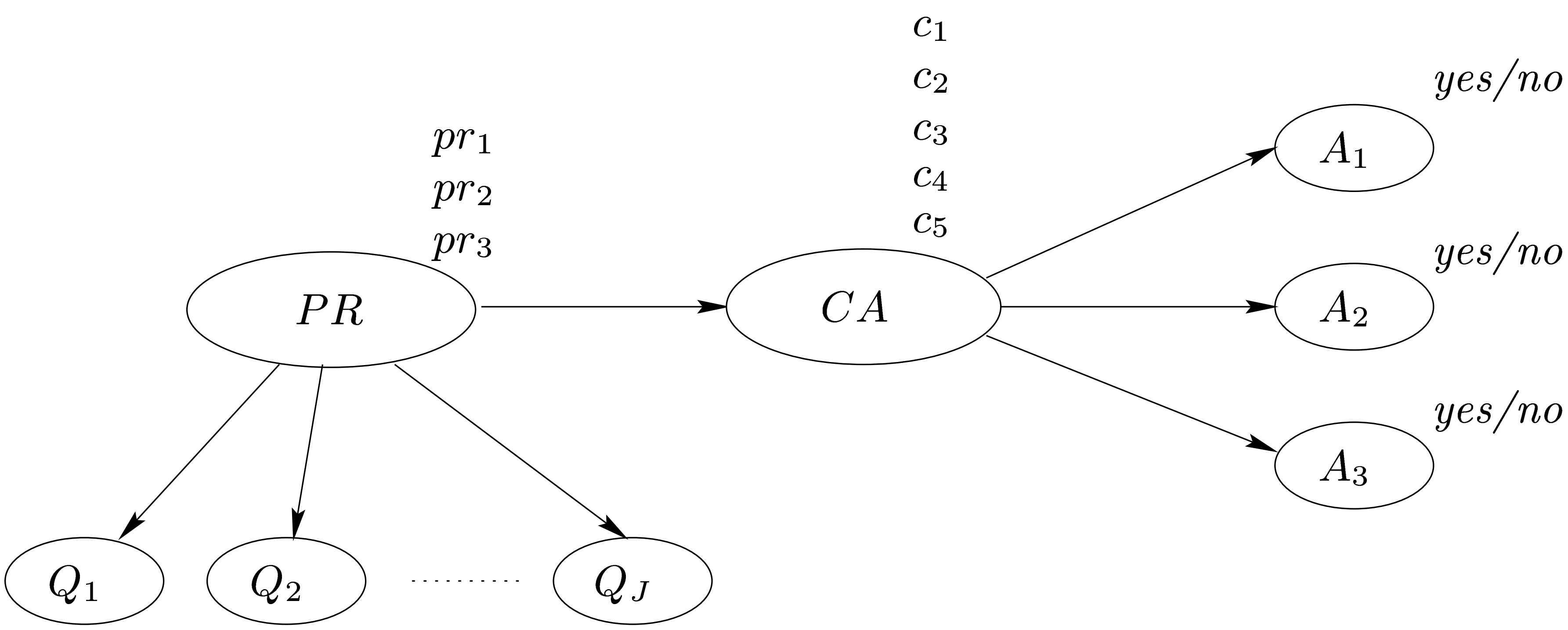
The complexity of the proposed procedure is $O(|\mathcal{A}|^2 \times |\mathcal{C}|)$,
$|\mathcal{A}|$ is the number of different actions,
$|\mathcal{C}|$ is the number of different causes over all models.

$$P(A = yes \mid h) \quad := \quad \sum_{c \in pa(A)} P(A = yes \mid CA = c) \cdot P(CA = c \mid h)$$

is generally different from

$$\begin{aligned} P(A = yes \mid h) \quad &:= \quad \sum_{j \in \{1,2,\ldots N\}} P_j(A = yes \mid h) \\ &:= \quad \sum_{j \in \{1,2,\ldots N\}} \sum_{c \in pa_j(A)} \begin{array}{c} P_j(A = yes \mid CM_j = c) \\ \cdot P_j(CM_j = c \mid h) \end{array} \end{aligned}$$

The second formula would disproportionally favour actions solving causes that are contained in more models.


c_1
c_2
c_3
c_4
c_5
yes/no
pr_1
pr_2
pr_3
A_1
yes/no
PR
CA
A_2
yes/no
A_3
Q_1
Q_2
Q_J

1. A domain expert provides $P(CA' = c_\ell \mid PR = pr_k)$, proposes set of questions $\mathcal{Q}$, and $P(Q_j = q_j \mid PR = pr_k)$. Set $h := \emptyset$.

2. Derive $P(PR = pr_k), k \in \{1, 2, \ldots, K\}$ from the user's problem description.

3. Ask the user the most informative question $Q_j \in \mathcal{Q}$ given the history h. Record the answer q_j.

4. For each $pr_k, k \in \{1, 2, \ldots, K\}$ compute

   $$P(pr_k \mid h \cup \{Q_j = q_j\}) \quad := \quad \frac{P(Q_j = q_j \mid PR = pr_k) \cdot P(pr_k \mid h)}{\sum_{k=1}^{K} P(Q_j = q_j \mid PR = pr_k) \cdot P(pr_k \mid h)} \quad .$$

   Set $h := h \cup \{Q_j = q_j\}$.

5. Decide whether you ask more questions. If yes, go to step 3, else in the individual SACSO models initialize $P(CA = c_\ell \mid h)$ for all $c \in \mathcal{C}$ as

   $$P(CA = c \mid h) \quad = \quad \sum_{k=1}^{K} P(CA = c \mid PR = pr_k) \cdot P(PR = pr_k \mid h) \quad .$$