Concurrency: Theory, Languages and Programming

– Proofs in CCS –

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The Scheduler Problem

- ☐ informal specification
- ☐ ***specification*** as *sequential* process expression
- ☐ ***implementation*** as *concurrent* process expression
- ☐ comparison between specification and implementaton
  - proofs using ABC
  - proofs "by hand" (very close to [§ 7.3])

Scheduler, Informally [Mil99, § 3.6]

- ☐ a set of n processes $P_i, 0 \leq i \leq n-1$ is to be scheduled
- ☐ P_i starts by sync'ing on a_i with the scheduler
- ☐ P_i completes by sync'ing on b_i with the scheduler
- ☐ **(1)** each P_i *must not* run two tasks at a time
- ☐ **(2)** tasks of different P_i *may* run at the same time
- ☐ a_i are required to occur cyclically (initially, 1 starts)
- ☐ for each i, a_i and b_i must occur cyclically
- ☐ **(3)** maximal "progress":
  the scheduling must permit
  any of the "buttons" to be pressed
  at any time provided (1) and (2) are not violated.

Formal Specification [Mil99, § 3.6]

$i \in \{0 \ldots, n-1\} \quad X \subseteq \{0 \ldots, n-1\}$

$\mathsf{S}_{i,X}(\vec{a}, \vec{b}) \stackrel{\text{def}}{=}$ scheduler, where i is next and every $j \in X$ is running

(* we omit the parameters in the following *)

$$\mathsf{S}_{i,X} \stackrel{\text{def}}{=} \begin{cases} \sum_{j \in X} b_j.\mathsf{S}_{i,X-j} & (i \in X) \\ \sum_{j \in X} b_j.\mathsf{S}_{i,X-j} + a_i.\mathsf{S}_{(i+1) \bmod n, X \cup i} & (i \notin X) \end{cases}$$

$$\mathsf{Scheduler}_n \stackrel{\text{def}}{=} \mathsf{S}_{0,\emptyset}$$

- ☐ draw the transition graph for $n = 2$
- ☐ show that the scheduler is never deadlocked
- ☐ what is the difference when dropping the case for $i \in X$?

Formal "Implementation" [§ 7.3]

$$
\begin{array}{rcl}
A(a,b,c,d) & \stackrel{\text{def}}{=} & a.c.b.\overline{d}.A \\
\hline
A(a,b,c,d) & \stackrel{\text{def}}{=} & a.C\langle a,b,c,d\rangle \\
C(a,b,c,d) & \stackrel{\text{def}}{=} & c.B\langle a,b,c,d\rangle \\
B(a,b,c,d) & \stackrel{\text{def}}{=} & b.D\langle a,b,c,d\rangle \\
D(a,b,c,d) & \stackrel{\text{def}}{=} & \overline{d}.A\langle a,b,c,d\rangle \\
\hline
\multicolumn{3}{l}{\vec{a} := a_1 \ldots, a_n,\ \ \vec{b} := b_1 \ldots, b_n\ \ \vec{c} := c_1 \ldots, c_n} \\
\hline
A_i(\vec{a},\vec{b},\vec{c}) & \stackrel{\text{def}}{=} & A\langle a_i, b_i, c_i, c_{i\ominus_n 1}\rangle \\
B_i(\vec{a},\vec{b},\vec{c}) & \stackrel{\text{def}}{=} & B\langle a_i, b_i, c_i, c_{i\ominus_n 1}\rangle \\
C_i(\vec{a},\vec{b},\vec{c}) & \stackrel{\text{def}}{=} & C\langle a_i, b_i, c_i, c_{i\ominus_n 1}\rangle \\
D_i(\vec{a},\vec{b},\vec{c}) & \stackrel{\text{def}}{=} & D\langle a_i, b_i, c_i, c_{i\ominus_n 1}\rangle \\
\hline
S(\vec{a},\vec{b}) & \stackrel{\text{def}}{=} & (\boldsymbol{\nu}\vec{c})\,(\,A_1\langle\vec{a},\vec{b},\vec{c}\rangle|D_2\langle\vec{a},\vec{b},\vec{c}\rangle|\cdots|D_n\langle\vec{a},\vec{b},\vec{c}\rangle\,)
\end{array}
$$

Formal "Implementation" (II) [§ 7.3]

$$
\begin{array}{rcl}
A(a,b,c,d) & \stackrel{\text{def}}{=} & a.c.(b.\overline{d}.A + \overline{d}.b.A) \\
\hline
A(a,b,c,d) & \stackrel{\text{def}}{=} & a.C\langle a,b,c,d\rangle \\
C(a,b,c,d) & \stackrel{\text{def}}{=} & c.E\langle a,b,c,d\rangle \\
E(a,b,c,d) & \stackrel{\text{def}}{=} & b.D\langle a,b,c,d\rangle + \overline{d}.B\langle a,b,c,d\rangle \\
B(a,b,c,d) & \stackrel{\text{def}}{=} & b.A\langle a,b,c,d\rangle \\
D(a,b,c,d) & \stackrel{\text{def}}{=} & \overline{d}.A\langle a,b,c,d\rangle \\
\hline
A_i & \stackrel{\text{def}}{=} & A\langle a,b,c_i,c_{i-1}\rangle \\
\ldots & & \\
S_n & \stackrel{\text{def}}{=} & (\boldsymbol{\nu}\vec{c})\,(\,A_1|D_2|\cdots|D_n\,)
\end{array}
$$

$\text{Scheduler}_n \stackrel{?}{\approx} S_n$

Proofs Using ABC

- ☐ model the specification for $n = 2$
- ☐ model the wrong (!) implementation for $n = 2$
- ☐ run the ABC
- ☐ analyze the transitions systems (using `step`)
- ☐ understand the problem
  w.r.t. the formal & informal specification
- ☐ model now the correct implementation for $n = 2$
- ☐ run the ABC
- ☐ understand the bisimulation relation that ABC has generated
- ☐ if time left, try out for $n = 3 \ldots$

Proofs "by Hand" (I)

means: "guessing" a bisimulation relation !

- ☐ draw the transition graph of S for $n = 2$
- ☐ generalize for greater $n \ldots$
- ☐ Observe: every reachable state is of the form

  $$(\boldsymbol{\nu}\vec{c})\,(\,Q_1|Q_2|\cdots|Q_n\,)$$

  where Q is one of A, B, C, D, E.
- ☐ Observe that in any state reachable from S_n
  only one of the Q is one of A, B, C,
  while **all other** Q are either of D, E.
- ☐ analyze the "meaning" of the those states

Proofs "by Hand" (II)

analyze the "meaning" of the following states for $n = 4$

$$(\boldsymbol{\nu}\vec{c})\ (\ D_1|E_2|A_3|E_n\ )$$

$$(\boldsymbol{\nu}\vec{c})\ (\ E_1|D_2|C_3|E_n\ )$$

Proofs "by Hand" (III)

Let $\{i\}, Y, Z$ be any partition of $\{0\ldots,n-1\}$.

$$A_{i,Y,Z} \stackrel{\text{def}}{=} (\boldsymbol{\nu}\vec{c})\ (\ A_i \mid \prod_{j\in Y} D_j \mid \prod_{k\in Z} E_k\ )$$

$$B_{i,Y,Z} \stackrel{\text{def}}{=} (\boldsymbol{\nu}\vec{c})\ (\ B_i \mid \prod_{j\in Y} D_j \mid \prod_{k\in Z} E_k\ )$$

$$C_{i,Y,Z} \stackrel{\text{def}}{=} (\boldsymbol{\nu}\vec{c})\ (\ C_i \mid \prod_{j\in Y} D_j \mid \prod_{k\in Z} E_k\ )$$

Note that $S_n = A_{0,\{1\ldots,n-1\},\emptyset}$.

Proofs "by Hand" (IV)

sing the Expansion Law, we show that:

$$A_{i,Y,Z} \sim a_i.C_{i,Y,Z} + \sum_{k\in Z} b_k.A_{i,Y\oplus k,Z\ominus k}$$

$$B_{i,Y,Z} \sim b_i.A_{i,Y,Z} + \sum_{k\in Z} b_k.A_{i,Y\oplus k,Z\ominus k}$$

$$C_{i,Y,Z} \sim \sum_{k\in Z} b_k.A_{i,Y\oplus k,Z\ominus k} + + \begin{cases} \tau.A_{i+1,Y\ominus(i+1),Z\oplus i} & \text{if } i{+}1 \in X \\ \tau.B_{i+1,Y,Z\ominus(i+1)\oplus i} & \text{if } i{+}1 \in Y \end{cases}$$

Proofs "by Hand" (V)

Let $\mathcal{R}$ be the relation containing the following pairs:

$$A_{i,Y,Z} \quad , \quad \mathsf{S}_{i,Z}$$

$$B_{i,Y,Z} \quad , \quad \mathsf{S}_{i,Z\oplus i}$$

$$C_{i,Y,Z} \quad , \quad \mathsf{S}_{i+1,Z\oplus i}$$

- ☐ $\mathcal{R}$ is a weak bisimulation (up to $\sim$).
- ☐ $\mathcal{R}$ contains the pair $(S_n, \mathsf{Scheduler}_n)$.
- ☐ Q.E.D.