Demonstration of an Automated Control Synthesis Tool for Manufacturing

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Robot Assembly Cell

Actuators:
- Conveyor: on, off
- Robot-turn: on-left, on-right, off
- Arm: on-up, on-down, off
- Electromagnet: on, off

Sensors: S1, S2, L-bin, R-bin, home, upstop, downstop, block-type
Current Practice in Control Design

User must:
- understand system and interactions
- write control code
- debug control code to confirm spec’s are met

Problems:
- different users/designers must each learn system
- unexpected interactions within code
- difficulty determining if controlled system satisfies all specs.
- repeated writing and debug ⇒ $$\$$$$

Current practice is inadequate when frequent modifications required.
**Spectool**

*Spectool:* Software tool for automatic synthesis of control code for manufacturing systems.

Inputs models of system components and high-level description of desired state behavior.

Outputs executable control program.
**Condition Models**

- *Conditions* are signals. Output conditions depend on state. Input conditions influence state change.

- Discrete state represented by condition Petri Net. Places output condition signals, transitions enabled by condition signals.

- Modular

- Concurrent

- Avoids state explosion of “remembering” past events
Condition System Model

AllC: **Universe of Condition Labels:**
includes negations, c, ¬c

\( P_G, T_G, A_G \): defines Petri Net
\( C_G \) maps conditions to places, transitions

Output conditions depend on state:
\[ g(m) = \{ c \mid c \in C_G(p) \text{ for some marked } p \} \]
\( C_{out,G} \) is set of all output conditions

Next-state set \( f(m,C) \) depends on input conditions:
Transition set \( T \) fires only if:
- state enabled (input places of \( T \) marked)
- conditions in \( C_G(t) \) are true (\( \forall t \in T \))

Resulting marking: (standard PN rule)
\[ m'(p) = m(p) + |^{(t)}p \cap T| - |p^{(t)} \cap T| \]
Control Synthesis Theory

Requires model of system capabilities in order to synthesize control.

**Synthesis Goal:** Given specifications of desired closed loop operation and model of plant capabilities, *automatically* determine a feedback controller to achieve the desired operation specifications.

- control is *synthesized to be correct.*
- changes in specifications give automatic revision of control
- plant model also useful for simulation and analysis

*Synthesis goal requires theory of techniques and tools that can provably guarantee satisfaction of operation specifications.*
Control problem

- Control goal: Develop control to achieve high-level sequencing specifications
  - Control synthesis problem is determining the low-level interactions necessary to achieve the high-level spec.
  - Control issue is filling in the details

- Key point:
  Control as *navigator*
  vs.
  control as *traffic-cop*
Synthesized Control Blocks

- **Control synthesis problem** is determining the low-level interactions necessary to achieve the high-level spec.
  - **Control issue** is filling in the details

- Control synthesized for individual components. Two types of blocks:
  - **ActionBlock**: drive component to target condition
  - **MaintainBlock**: keep component in target condition

- **Blocks combined**
  - Sequentially -- for sequential control specifications
  - Hierarchically -- for dependent components
ActionBlock Synthesis

Plant model:

Synthesized ActionBlock for target “x”
Plant model:

Synthesized MaintainBlock for target “x”
Control Specification

- Specification is a condition system describing desired plant behavior.

- Outputs of places in specs are used as targets in developing action and maintain blocks.
Code Synthesis

CodeMaker: Individual Actionblock and Maintainblock net files are converted into C++ code. Top level spec also converted into C++ code.

MakeMaker: automatically compiles project into executable

```c++
void SCO_doA_CHomeH_Class::StateEval()
{
    ...
    if ((SCO_doA_CHomeH_List[0]) )
    {
        if ((pCondTable->GetConditionValue("doA_CHomeH") > 0))
        {
            SCO_doA_CHomeH_List[0] = false;
            pCondTable->UpdateConditionValue("Idle_CHomeH", -1);
            SCO_doA_CHomeH_List[1] = true;
        }
    }
    if ((SCO_doA_CHomeH_List[1]) )
    {
        if ((pCondTable->GetConditionValue("CHomeH") > 0))
        {
            SCO_doA_CHomeH_List[1] = false;
            SCO_doA_CHomeH_List[2] = true;
            pCondTable->UpdateConditionValue("Cmpl_CHomeH", 1);
            pCondTable->UpdateConditionValue("doM_CHomeH", 1);
        }
    }
    if ((SCO_doA_CHomeH_List[3]) && (pCondTable->GetConditionValue("Cmpl___doA_MotorRight") > 0) &&
(pCondTable->GetConditionValue("Cmpl___doA__qNOTq__MotorLeft") > 0))
    {
        if ((pCondTable->GetConditionValue("CHomeH") > 0))
        {
            SCO_doA_CHomeH_List[2] = true;
            pCondTable->UpdateConditionValue("Cmpl_CHomeH", 1);
            pCondTable->UpdateConditionValue("doM_CHomeH", 1);
            SCO_doA_CHomeH_List[3] = false;
            pCondTable->UpdateConditionValue("doA_MotorRight", -1);
            pCondTable->UpdateConditionValue("doA__qNOTq__MotorLeft", -1);
        }
    }
    ...
}
```
- Executable interacts with hardware through shared memory interface
  - device independent synthesis
Issues and Current Work

- Specification Complexity:
  - current software version: literal vs. “implied” specs
- Model Delays:
  - solution: condition signals that refer to timing objects
- Unobserved states:
  - solution: automated synthesis of state observers (WODES2000)
- Coordination of synthesized control blocks
  - current work on synthesis of supervisor over control