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Evaluation of a Guideline by Formal Modelling of a Cruise Control System in Event-B

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deploy

Overview

- Managing complexity
  - Abstraction and refinement
  - Event-B and Rodin
  - Sources of system complexity
- Outline of a “Cookbook” for abstraction and refinement
- Applying “cookbook” to Cruise Control System
  - Initial Model
  - Six level of Refinement
- Evaluation and Future Work

Abstraction

- Abstraction can be viewed as a process of simplifying our understanding of a system.

- The simplification should
  - focus on the intended purpose of the system
  - ignore details of how that purpose is achieved.

- The modeller should make judgements about what they believe to be the key features of the system.

- Working with system level reasoning:
  - Involves abstractions of *overall* system not just software components
  - Emphasise left hand of V process

Refinement

- Refinement is a process of enriching or modifying a model in order to
  1. augment the functionality being modelled, or
  2. explain how some purpose is achieved

- We can perform a series of refinement steps to produce a series of models M1, M2, M3, ...

- Consistency of a refinement:
  - We use proof to verify the consistency of a refinement step
  - Failing proof can help us identify inconsistencies in a refinement step

Event-B (Abrial)

- State-transition model (like ASM, B, VDM, Z)
  - set theory as mathematical language
- Refinement (based on action systems by Back)
  - events: guarded actions
  - data refinement
  - one-to-many event refinement
  - new events (stuttering steps)
- Proof method
  - Refinement proof obligations (POs) generated from models
  - Automated and interactive provers for POs

Rodin Open Tool Platform

- Extension of Eclipse IDE
- Open source development
- Rodin Builder manages:
  - Well-formedness + type checker
  - Consistency/refinement Proof Obligation generator
  - Proof manager: automated and interactive proof
  - Propagation of changes
- Extension points supports plug-ins
  - model-checking, simulation, code generation, UML-B,…

www.event-b.org

Sources of System Complexity

- control laws
  - change acceleration to maintain speed, …
- operator commands
  - change target speed, suspend, resume, …
- operator interface
  - buttons, pedals, gearstick …
- interaction with other features
  - engine management, braking, gearbox,…
- faults and fault management
  - sensor faults, actuator faults, etc, …
- architecture
  - multi-tasking, distribution, bus, signal evaluation, sensors, actuation, …

- Where to start modelling?
- What is the right abstraction?
- How do we treat various sources of compexity?

“Cookbook” for control systems (Butler)

- Guidelines for abstraction and refinement of control systems in Event-B
- *Influenced* by Parnas 4-variable model
- Abstract models focus on environment phenomenon
- Central role of system operator (e.g., driver) is addressed
- Refinement patterns for introducing
  - sensing
  - actuation
  - command activation

Four-variable model (Parnas)

- Environment variables
  - Monitored variables *(speed)*
  - Controlled variables *(acceleration)*

- Controller variables
  - Input variables *(sensed speed)*
  - Output variables *(accelerator actuation value)*

Requirements

- NAT (for nature)
  - describes how monitored variables are influenced by controlled variables (*assumptions*)

- REQ
  - describes required values of controlled variables in response to monitored variables (*guarantees*)

Design

In design, we introduce

- IN
  - relates monitored variables to input variables

- OUT
  - relates output variables to controlled variables

Patterns

- Modelling patterns
  - Automonous controller (*NAT and REQ*)
  - Commanded controller

- Refinement patterns
  - Separate control and actuation (*OUT*)
  - Separate sensing and control (*IN*)
  - Introduce command activation

Autonomous controller model

- Variables
  - *Monitored* variables
  - *Controlled* variables
- Events
  - *Plant* events: modify the monitored variables (NAT)
  - *Control* events: modify the controlled variables (REQ)

Commanded Controller Model

- ***Commanded variable:*** value determined by operator (*e.g., target speed, cruise status*)

- ***Command:*** modify a commanded variable (*e.g., tip-up, switch-off*)

- Extension of autonomous model with
  - Commanded variables (cmv): can influence control events
  - Command events (CMD): modify commanded variables

Applying modelling pattern to cruise control

- **Monitored**: speed
- **Controlled**: acceleration
- **Operator**: target speed, status (on, standby, off)

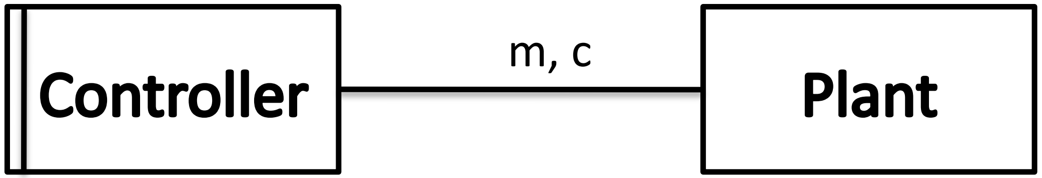
- Feature elaboration refinements:
  - elaborate events for changing target speed
  - elaborate events for changing status through acceleration/clutch or braking pedals
  - elaborate events for gears and gear change
  - clear identification of different cases

Introducing pedals (in more detail)

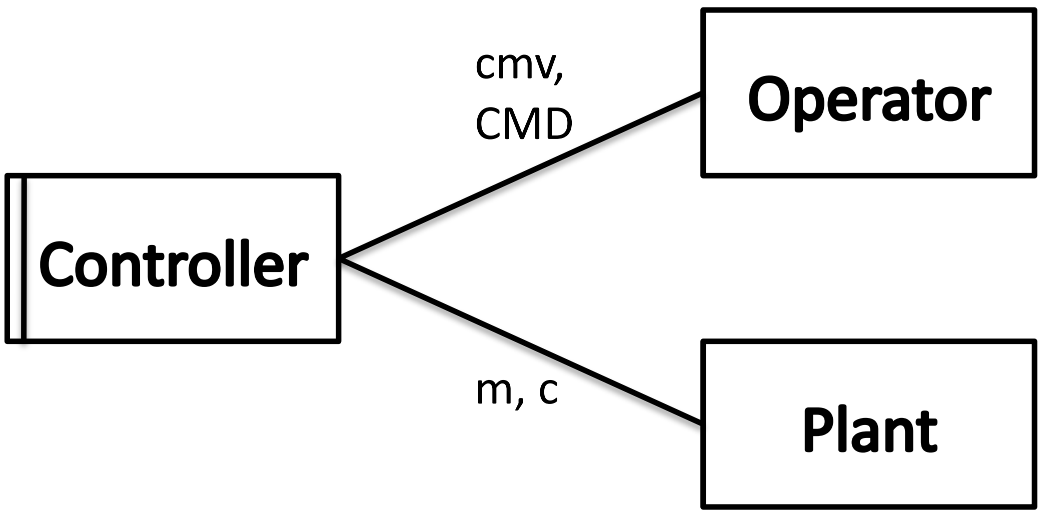
- Pressing accelerator → temporary suspension of CCS.
- Releasing accelerator → CCS regain the control of car speed.
- Pressing brake or clutch → permanent suspension.
- Driver can suspend CCS to regain the control of car speed.

Diagrammatic representation (using Jackson Problem Frames)

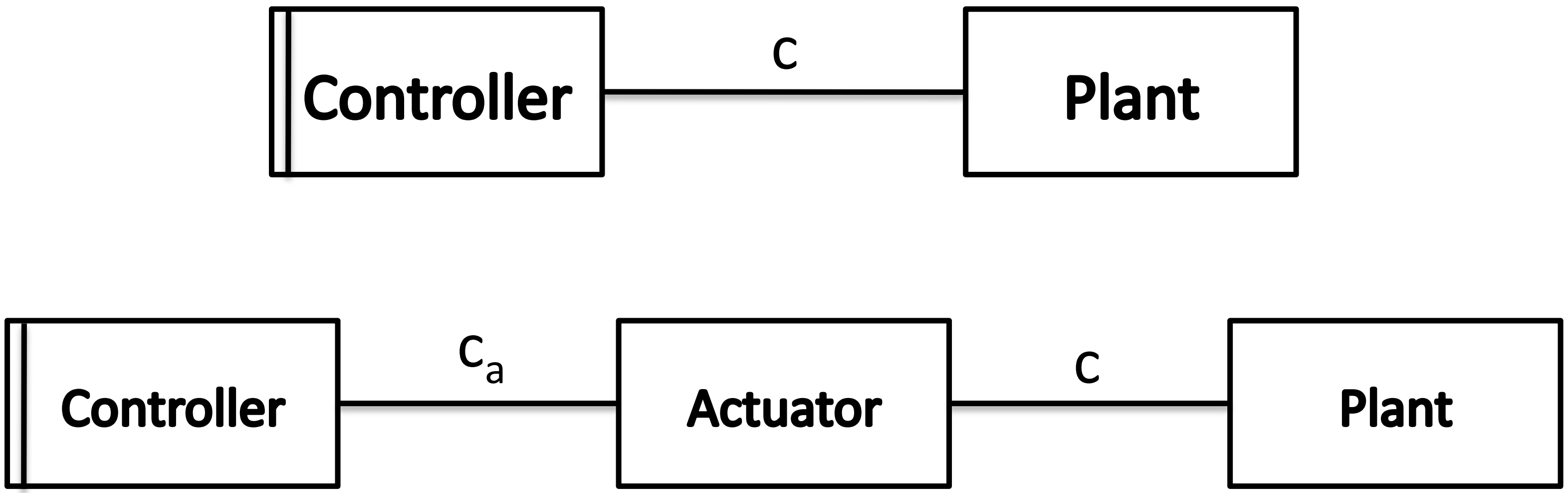
Autonomous Controller



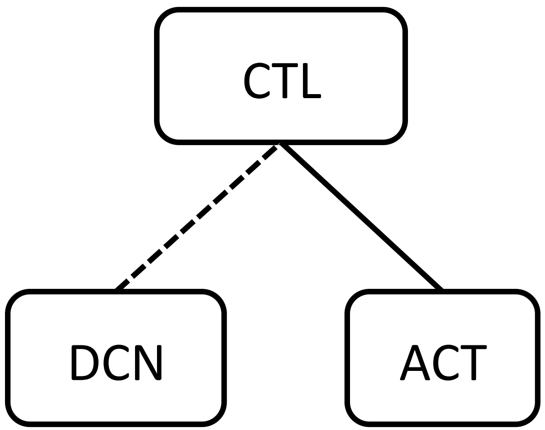
Commanded Controller



Refinement pattern I : separate control and actuation (OUT)



Event refinement:



Refinement pattern I

- For controlled variable c, introduce *actuation* variable c_a

- Abstract control events: CTL

  CTL = $c := E(m,c)$

- Refined events

  DCN = $c_a := E(m, c_a)$ /* refines skip */

  ACT = $c := c_a$ /* refines CTL */

Refinement pattern Ib

- More generally, CTL will have several cases:

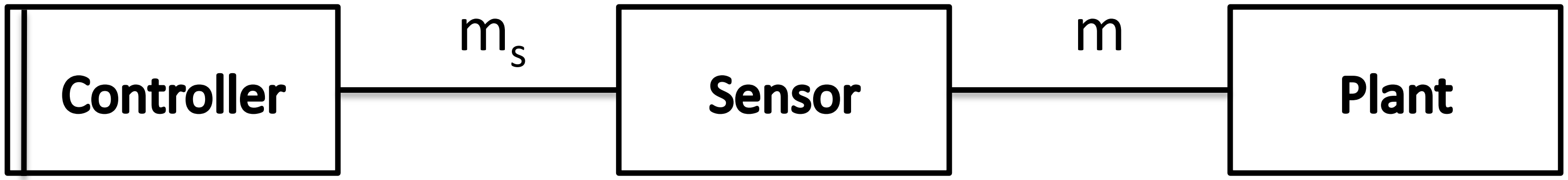
CTL_i = **when** $G_i(m,c)$ **then** $c := E_i(m,c)$ **end**

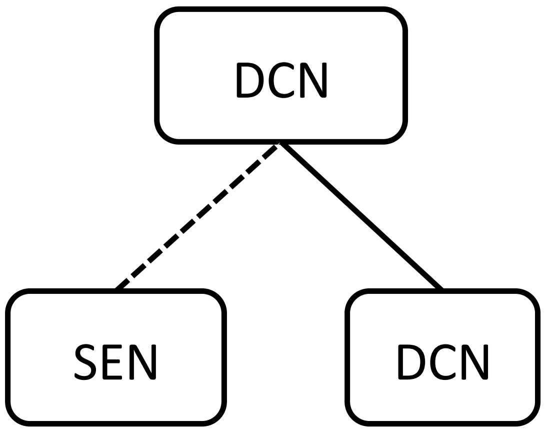
- Cases will be in the refined decision events:

DCN_i = **when** $G_i(m, c_a)$ **then** $c_a := E_i(m, c_a)$ **end**

ACT = $c := c_a$ /* refines merge of all CTL_i */

Refinement pattern II :
separate sensing and control (IN)





Refinement pattern II

- For monitored variable m, introduce *sensed* variable m_s

- Abstract decision events:

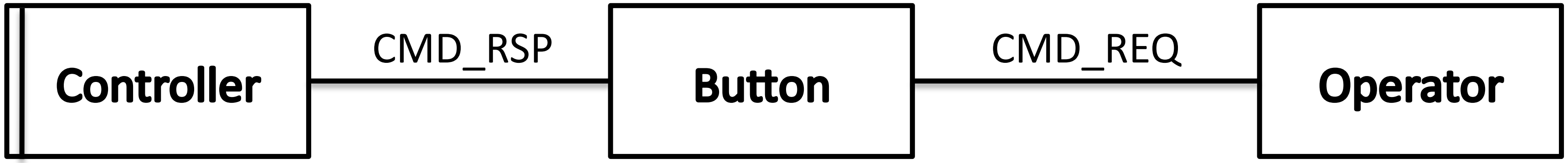
  DCN_i = **when** $G_i(m, c_a)$ **then** $c_a := E_i(m, c_a)$ **end**

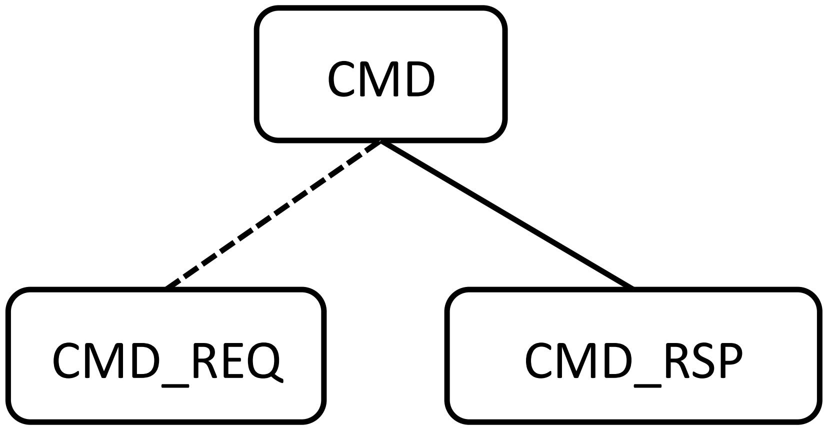
- Refined events

  SEN = $m_s := m$

  DCN_i = **when** $G_i(m_s, c_a)$ **then** $c_a := E_i(m_s, c_a)$ **end**

Refinement pattern III : introduce operator requests





Cruise control – applying refinement patterns

1. Introduce actuation
   – distinguish determination of acceleration (internal) from actuation of acceleration (external)
2. Introduce sensing
   – distinguish actual speed from sensed speed stored in controller
3. Introduce buttons
   – Separate operator request for some command from the effect of that command
   – Deal with overloading multiple functions on same button

Evaluation of cookbook

- Identifying monitored, controlled and commanded variables at the abstract level
  - Provides a lot of structure and focus for modeller
- Introducing sensing, actuation and buttons using patterns was straightforward
- Proofs were all automatic
  - because of small refinement steps
  - main proofs: correctness of refinements
- No treatment of feature augmentation in original guideline
- Variable categorisation sometimes fuzzy
  - e.g., gear is monitored from CCS viewpoint, but commanded from a system viewpoint
- Treatment of buttons in original guideline not general enough

Future Work

- Decomposition to distributed architecture: separation of the platform, the environment and the software application concepts.
- Traceability links between requirements and Event-B models
- Addressing limitations of the guidelines
  - timing
  - fault tolerance
  - operator command interface (buttons, pedals, …)
  - operator display
- Application to other automotive and avionics case studies

Real time…
… or lack of real time

- Control goal: maintain vehicle speed within bounds
- Control strategy: sample speed periodically and adjust acceleration according to some control laws

- We focus on modelling and refining strategy and also dealing with operator interactions
  - for this we don't need real-time, only event ordering

- Our experience with CCS is that operator interaction is a major source of complexity
  - *it is all discrete so is easily dealt with using Event-B*

- Verifying the strategy satisfies the goal does require real-time