From Worlds to Machines

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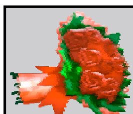


A very personal tribute first ...

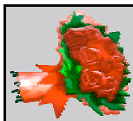
- 1979: Research on concurrency at Philips Labs

  Fixpoint calculation of safe invariants

  $D = D \wedge I \wedge \vee_i \, wp\,(S_i, D)$

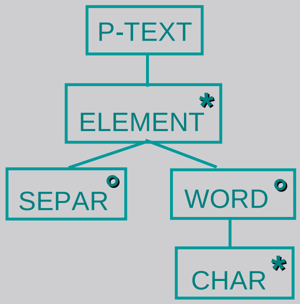
- 1980: Teaching COBOL at University of Namur

```
ENVIRONMENT DIVISION.  ...
DATA DIVISION.
  01 PRINT-LINE.
     02 NUM OCCURS 10 PIC ZZZ9 SYNCHRONIZED.
PROCEDURE DIVISION.
 PTABLE.
   PERFORM PLINE VARYING LN FROM 1 BY 1 UNTIL LN > 50.
   STOP RUN.
 PLINE.
   MOVE SPACES TO PRINT-LINE.
   PERFORM PROCESS-ELEMENT UNTIL EOF.
```



JSP saved me from intellectual trauma

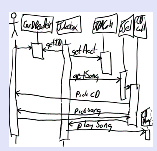
- Yes, we can... (make ugly things elegantly)

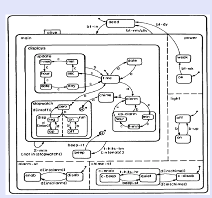


While *moreElem* do
    if *Separator* then ...
    orif *Word* then
        while *moreCharact* do ...

- A real *method* for structured programming
- Deep thoughts on resolution of structure clashes
- And ... COBOL as a target language!

From programs to specs to requirements



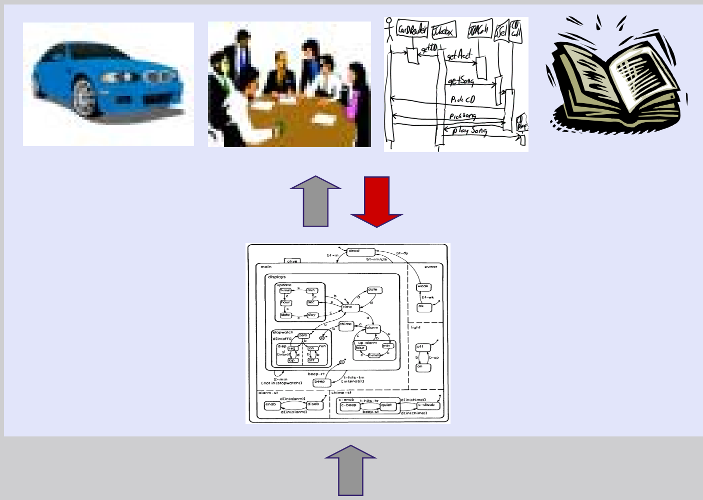


World

Machine

MOVE SPACES TO OUTPUT.
PERFORM PROCESS-EVENT UNTIL TIMEOUT.

This talk

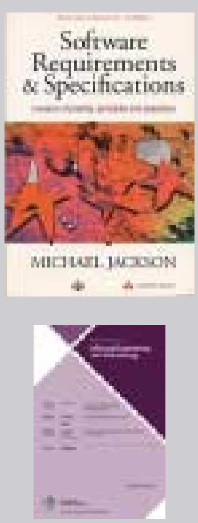


World

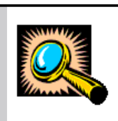
Machine

MOVE SPACES TO OUTPUT.
PERFORM PROCESS-EVENT UNTIL TIMEOUT.

Problem world *vs.* machine solution

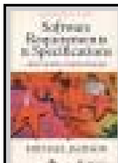


- **World**: problematic part of real-world
  - Organizational & physical components
- **Machine**: abstraction for what needs to be developed to solve the problem
- Requirements engineering (RE) is concerned with ...
  - the desired machine's effect on the problem world
  - the *relevant* properties of this world

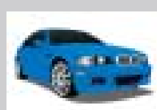


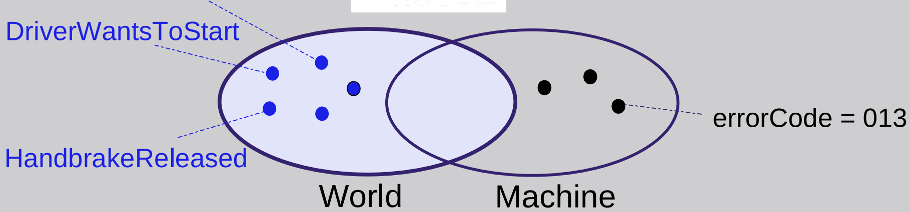
Outline

- Anchoring the Machine on the Problem World
- Characterizing the Problem World
- Delimiting and structuring the Problem World
- Chaining satisfaction arguments
- Deriving specifications from requirements
- Questioning statements
- Reusing problem schemas



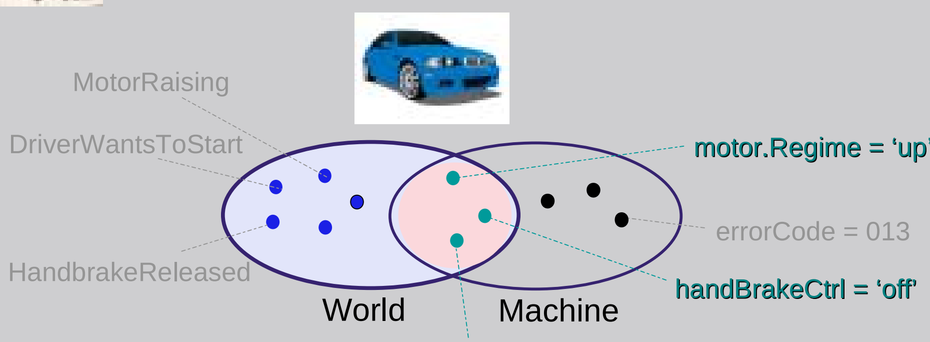
Anchoring the Machine on the Problem World





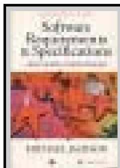
- A problem: handbrake release can be inconvenient
- The world and the machine have their own phenomena

Anchoring the Machine on the Problem World

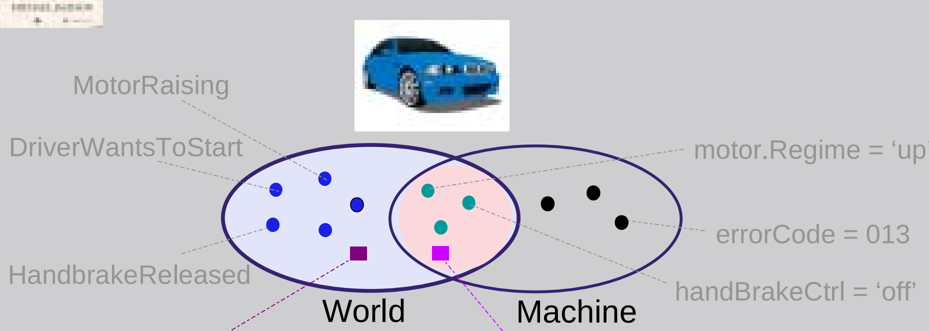


Anchoring through **shared** phenomena ...

- monitored or controlled: by the world or by the machine
- define the world-machine boundary



Anchoring the Machine on the Problem World



Requirements:
constrain world phenomena
MotorRaising ⟶ HandbrakeReleased

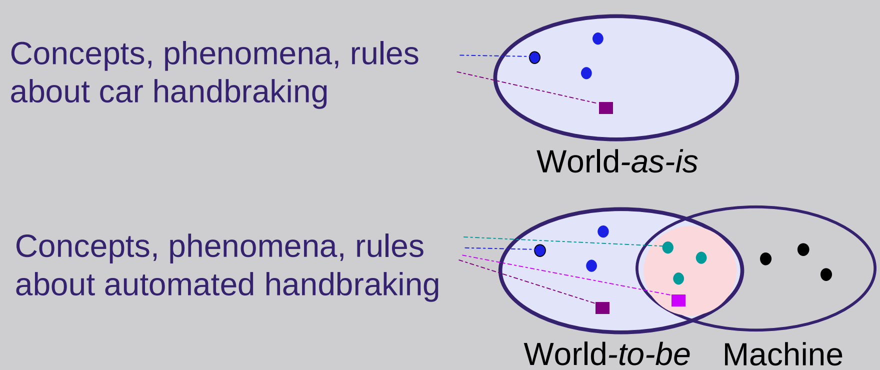
Specifications:
constrain shared phenomena
motor.Regime = 'up' ⟶ handBrakeCtrl = 'off'

Impact

- Clarification of real nature of requirements
  - long-standing confusion: reqs *vs.* specs, stakeholder vocabulary *vs.* developer vocabulary
- Machine as a refinable abstraction
  - may include software and I/O devices first, then only the software to be developed
- Led us to...
  - a realizability criterion for responsibility assignment
  - explicit agent interfaces for inductive inference of goals from scenarios

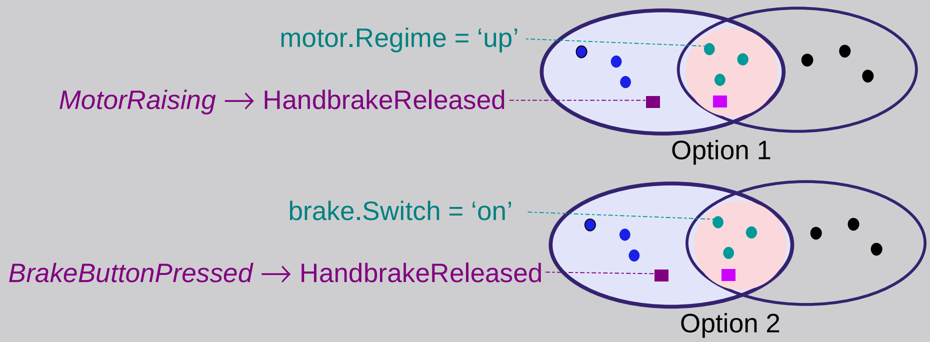
W & M revisited: the world-as-is and the world-to-be

Domain analysis and requirements elicitation involve two versions of the world



W & M revisited: alternative machine solutions

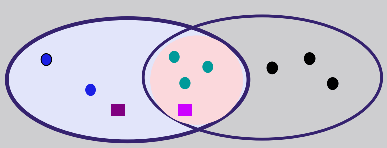
- Requirements evaluation involves multiple options
- Alternative options yield different shared phenomena



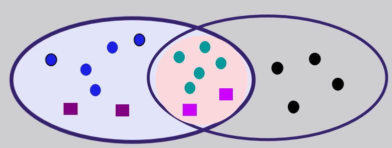
The World-Machine boundary is not fixed when RE starts

W & M revisited: world variations and evolutions

- Product lines involve multiple world-machine *variants*

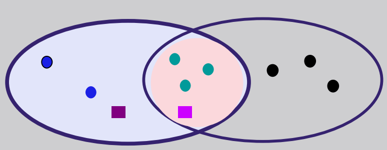


Handbraking in Class ***E*** car

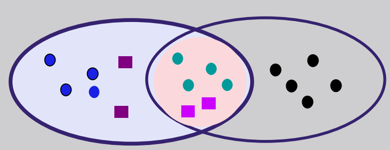


Handbraking in Class ***S*** car

- Requirements prioritization & evolution management involve world/machine *to-be-next*



Class *E* handbraking, **2009 model**

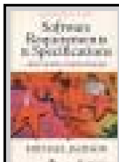


Class *E* handbraking, **2011 model**

Outline

- Anchoring the Machine on the Problem World

- Characterizing the Problem World
- Delimiting and structuring the Problem World
- Chaining satisfaction arguments
- Deriving specifications from requirements
- Questioning statements
- Reusing problem schemas



Characterizing the Problem World

- Typology of statements about the world
  - **Descriptive**: natural laws, physical constraints, etc

    A car's motor regime *is* raising when the air conditioner starts
  - **Prescriptive**: desired, to be enforced

    Handbrake *shall* be released when the car's motor regime is raising
  - **Definition**: for concepts/terms, no truth value

    A car's motor regime is said to be raising if it increases by *X* above neutral level
- For formalized statements:
  - **Designation**: meaning of atomic predicate/terms, in terms of **world** objects and phenomena

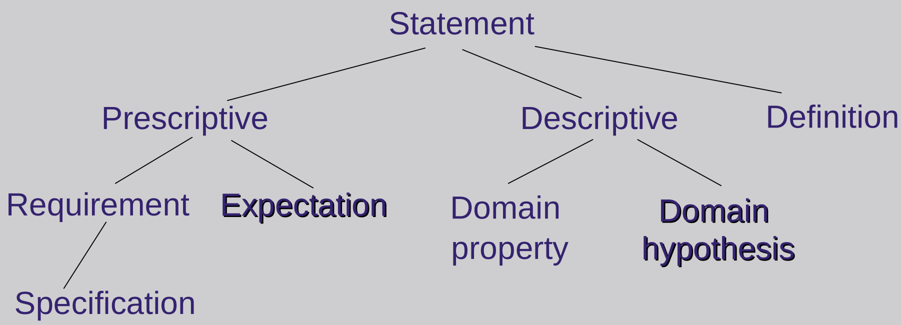
Impact

- Important clarification: requirements are prescriptive, domain properties are descriptive
  - We can negotiate, weaken, find alternatives to prescriptive statements only
- Definitions & designations are essential for precision and conciseness
- Led us to use descriptive properties for...
  - proving goal refinements & operationalizations
  - deriving obstacles & conditions for conflict

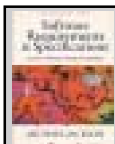
Statement typology revisited: assumptions as first-class citizens

- Assumptions on problem world are frequently made in RE
- More volatile, more subject to adequacy checking
- Play important role in satisfaction arguments, risk analysis, option selection, traceability management
- Some are prescriptive, others are descriptive
  - The driver shall press the acceleration pedal if she wants to start (expectation)
  - Handbrakes are never used under -40° (domain hypothesis)

Statement typology revisited

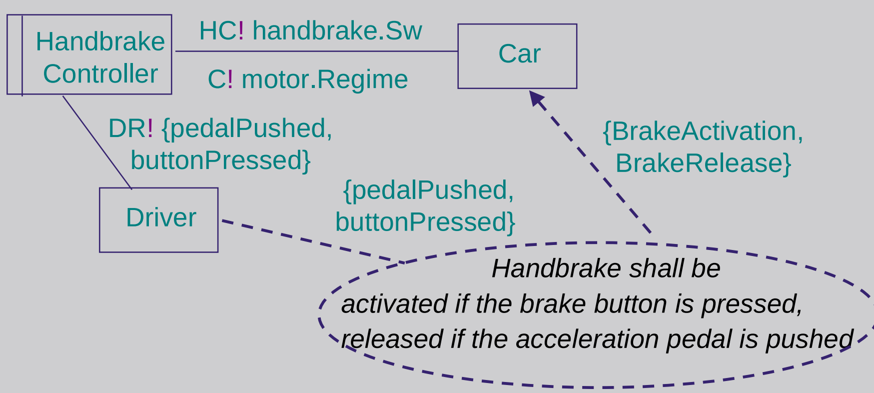


Expectations on people are often documented in user manuals



Delimiting & structuring the Problem World

- **Scope**: limited to subject matter
- **Structure**: problem diagram showing components, interfaces, requirements



Issues and perspectives

- Bounding the problem world is sometimes hard
  - Analysis of feature interactions
    => components beyond subject matter
    e.g. handbrake control + *air conditioning* control ?
  - Security threat analysis => malicious components
    e.g. handbrake release by car robber ?
  - Open systems => what foreign components ?
- Further structuring of problem diagrams might be required for scaleability
  - Decomposition, specialization, refinement, ...
    + proof obligations

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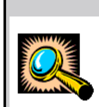


- Chaining satisfaction arguments
- Deriving specifications from requirements
- Questioning statements
- Reusing problem schemas

Satisfaction arguments

- Need to show that the requirements will be met if the specs are met in view of domain properties and assumptions:

$$\{SPEC, ASM, DOM\} \models Req$$

SPEC: motor.Regime = 'up' → handBrakeCtrl = 'off'

ASM: motor.Regime = 'up' ↔ MotorRaising
handBrakeCtrl = 'off' ↔ HandbrakeReleased

\---

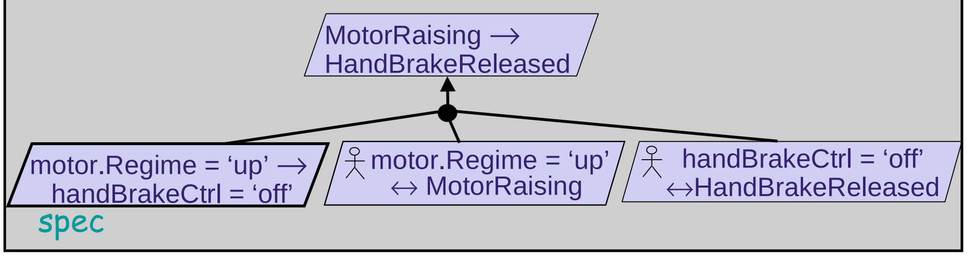
Req: MotorRaising → HandbrakeReleased

Impact

- Important role of satisfaction arguments
  - Verifying spec correctness wrt requirements
  - Making required domain properties & assumptions explicit (and questionable)
  - Managing traceability: if assumption no longer valid, specs linked to it by an argument must change accordingly

Chaining satisfaction arguments into argumentation trees

To show how specifications ensure higher-level concerns, and recursively



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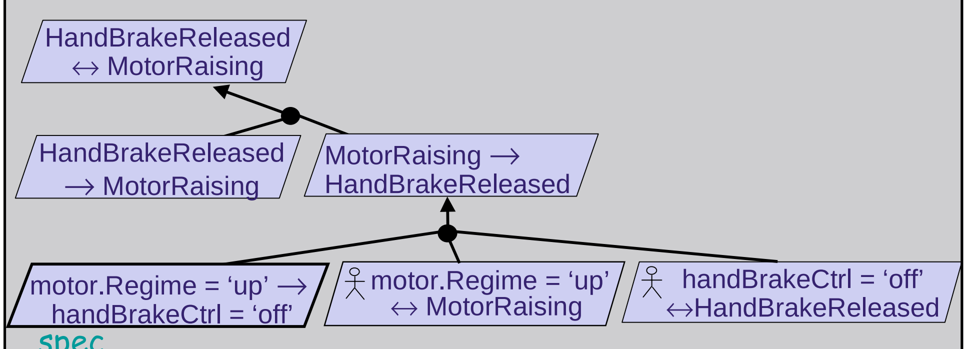

Chaining satisfaction arguments into argumentation trees

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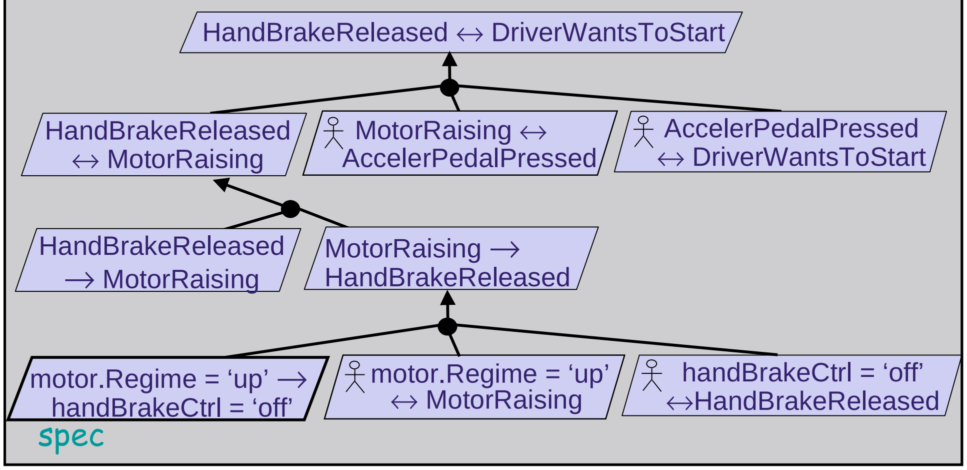


Deriving specifications from requirements

- General idea: incrementally replace non-shared phenomena in requirements by shared "images"
  - using domain properties, assumptions, satisfaction args
  - e.g. HandbrakeReleased --> handBrakeCtrl = 'off'
- Cf. turnstile control example in [ICSE'95]
- More difficult if requirements language and specification language are not the same
- Can this be made systematic ?

One solution: pattern-based derivation

- Patterns encode common refinement tactics
- Proved once for all

ReqOnUnMonitorableCondition

ReqOnMonitorable Condition

MonitorableCondition ↔ UnmonitorableCondition

instantiation

MotorRaising → HandBrakeReleased

motor.Regime = 'up' → HandBrakeReleased

motor.Regime = 'up' ↔ MotorRaising

Pattern-based derivation (2)

ReqOnUnControllableCondition

ReqOnControllable Condition

ControllableCondition ↔ UncontrollableCondition

instantiation

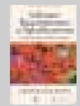
motor.Regime = 'up' → HandBrakeReleased

motor.Regime = 'up' → handBrakeCtrl = 'off'

handBrakeCtrl = 'off' ↔ HandBrakeReleased

spec

Questioning statements

- Critical domain properties & assumptions used in satisfaction args must be checked for adequacy
- Cf. A320 braking logic example in 
- More difficult for probabilistic statements

  S holds in *X*% of cases
- Can this be made systematic ?

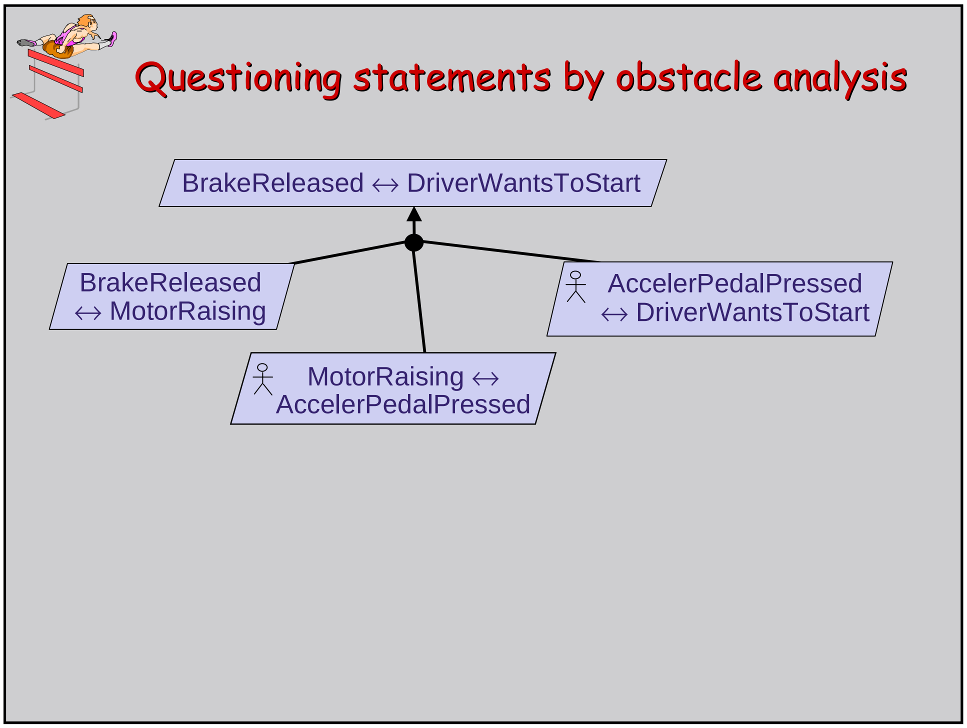
One solution: obstacle analysis

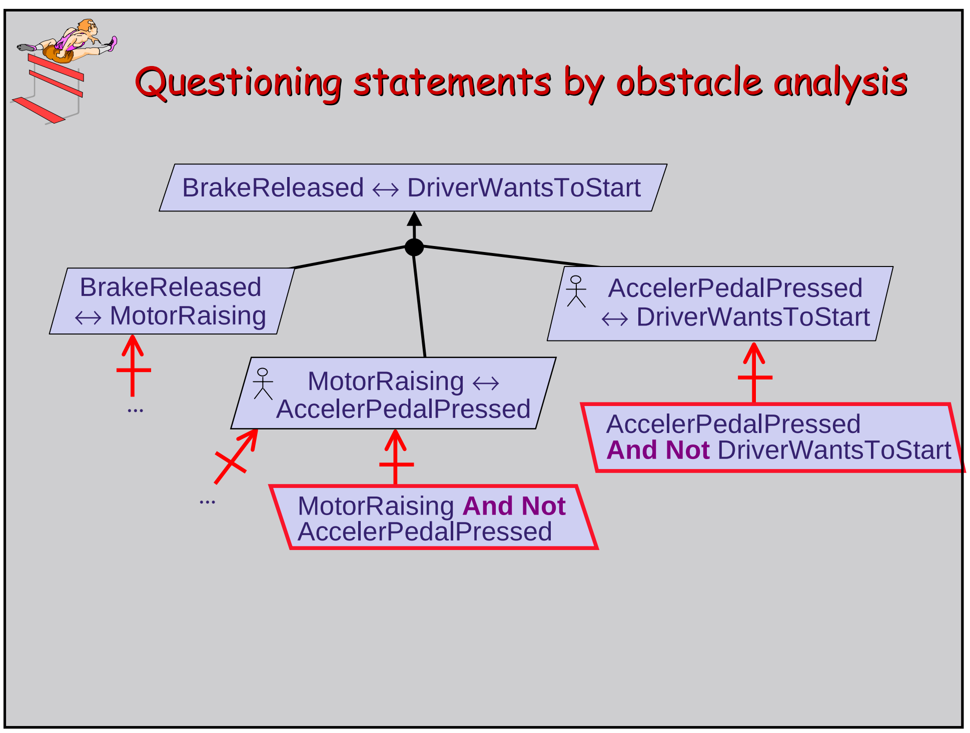
- Obstacle = condition for statement obstruction

  $\{O, Dom\} \models \neg S$ *obstruction*

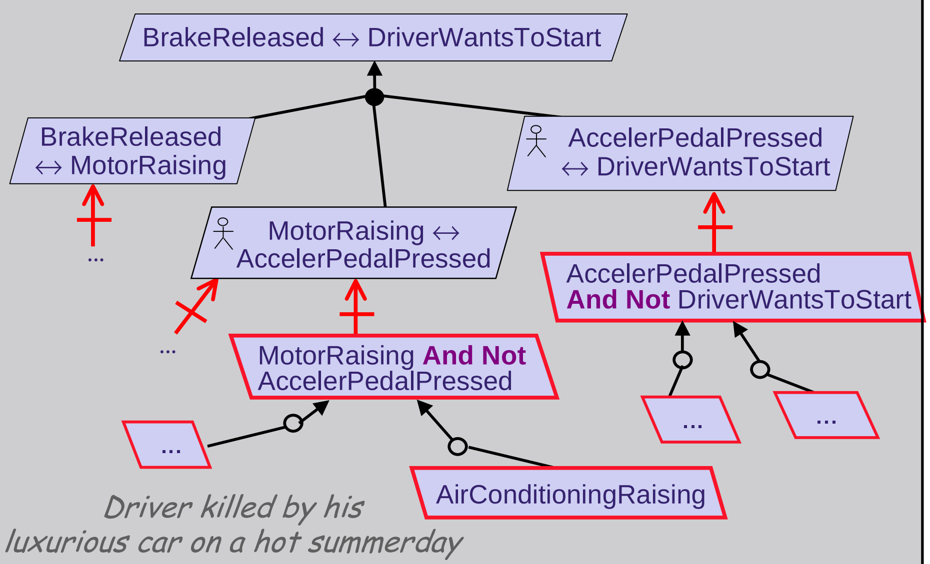
  $Dom \not\models \neg O$ *domain consistency*
- Obstacle analysis:
  1. **Identify** obstacles as preconditions for statement negation in view of domain properties

     → formal calculus, obstruction patterns
  2. **Assess** their likelihood and severity
  3. **Resolve** likely/critical ones (using available tactics)


Questioning statements by obstacle analysis
BrakeReleased ↔ DriverWantsToStart
BrakeReleased ↔ MotorRaising
AccelerPedalPressed ↔ DriverWantsToStart
MotorRaising ↔ AccelerPedalPressed


Questioning statements by obstacle analysis
BrakeReleased ↔ DriverWantsToStart
BrakeReleased ↔ MotorRaising
AccelerPedalPressed ↔ DriverWantsToStart
MotorRaising ↔ AccelerPedalPressed
...
AccelerPedalPressed And Not DriverWantsToStart
...
MotorRaising And Not AccelerPedalPressed

Questioning statements by obstacle analysis



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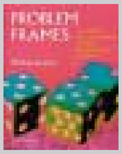
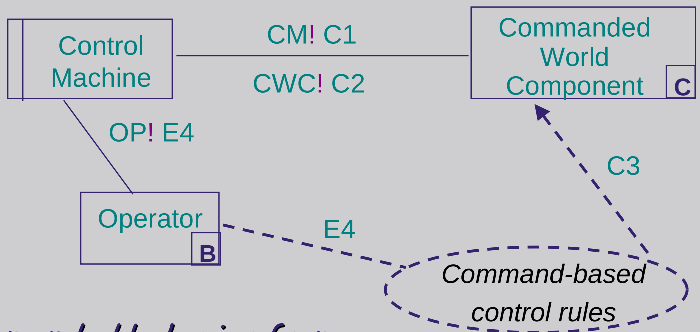
- **Reusing problem schemas**

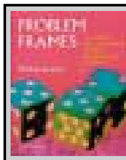


Reusing problem schemas

- Candidate world structures, reqs & specs can be derived by instantiating **problem patterns** captured by frame diagrams



Commanded behavior frame



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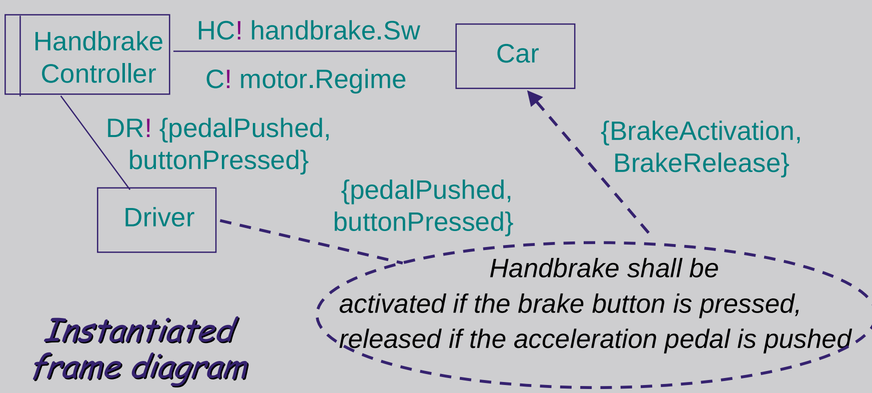
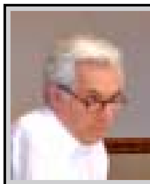


Instantiated frame diagram

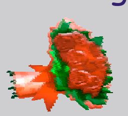
Problem reuse: challenges

- Schema descriptions should be sufficiently **rich** to enable reuse beyond structural information
- Reusable schemas should be sufficiently **specific** to enable transfer of useful discriminating features
- Perfect match is unfrequent
  => support for validation & adaptation of instantiated schemas ?
- Problem worlds generally combine multiple types of problem
  => mechanisms for composing schemas and instantiations ?



Conclusion

- Major contributions to a reference model for RE
- Significant clarification of ...
  - the complex relationship between problem worlds and machine solutions
  - the role of domain properties and satisfaction arguments
- Increasing impact on RE research, education, practice
- And... such elegance in thinking and writing...



Thanks, Michael !