Temporal Planning

Task Planning

Classical Planning: Limits

Instantaneous actions

No temporal constraints

No concurrent actions

No continuous quantities

Spacecraft Domain

Observation-1
- priority
- time window
- target
- instruments
- duration

Observation-2

Observation-3

Observation-4

…

Objective:
maximize science return

Spacecraft Domain

linked

Observation-1
- priority
- time window
- target
- instruments
- duration

Observation-2

Observation-3

Observation-4

…

angle between targets
⇒ turn duration

calibration
- target1
- target2
- …

consumables:
- fuel
- power
- data storage
- cryogen

Objective:
maximize science return

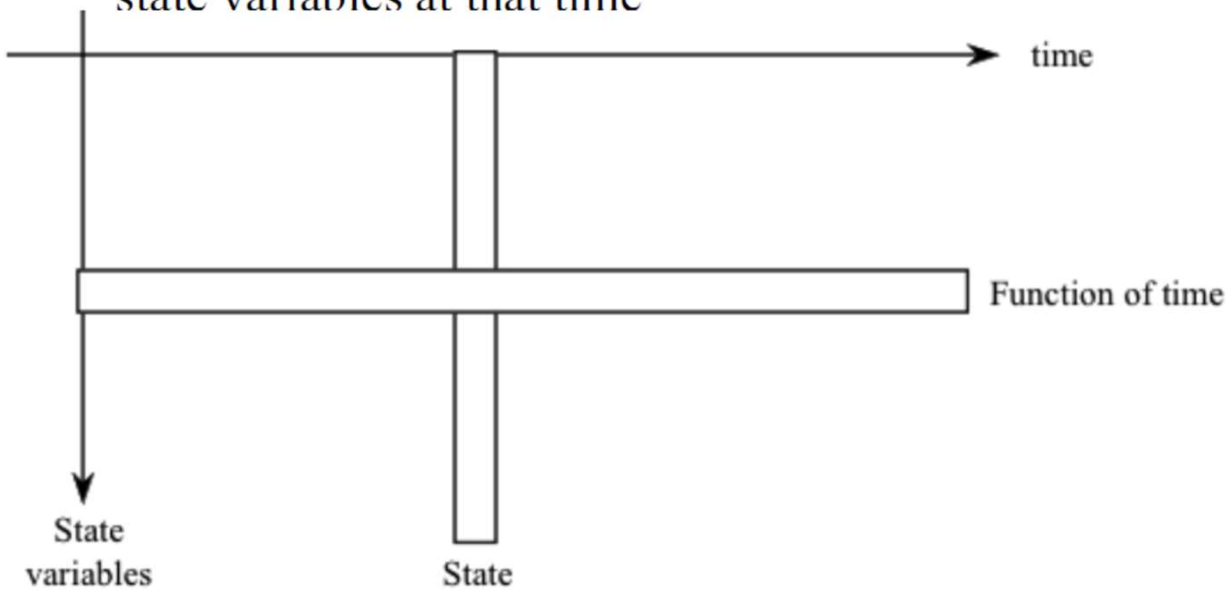
Based on slides by Dave Smith, NASA Ames

Extensions

- Time
- Resources
- Constraints
- Uncertainty
- Utility
- …

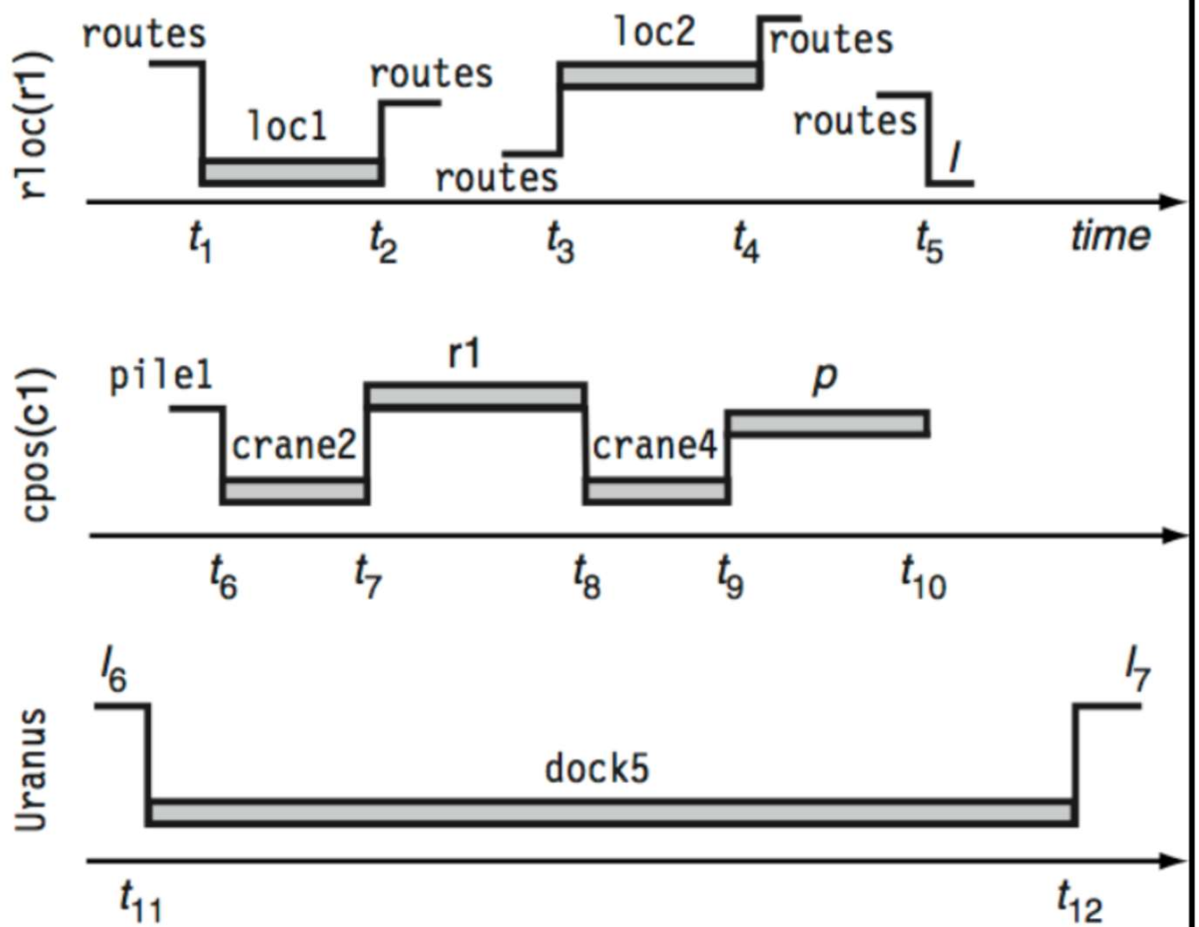
The Time-Oriented View

- We'll concentrate on the "time-oriented view": Sections 14.3.1–14.3.3
  - It produces a simpler representation
  - State variables seem better suited for the task
- States not defined explicitly
  - Instead, can compute a state for any time point, from the values of the state variables at that time



DWR Example

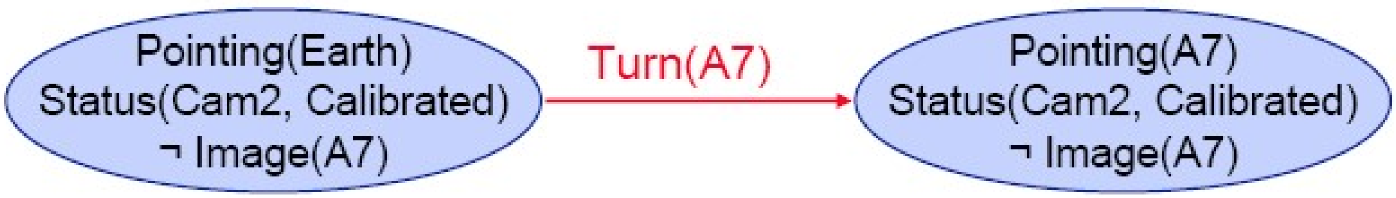
- robot r1
  - in loc1 at time t_1
  - leaves loc1 at time t_2
  - enters loc2 at time t_3
  - leaves loc2 at time t_4
  - enters l at time t_5
- container c1
  - in pile1 until time t_6
  - held by crane2 until t_7
  - sits on r1 until t_8
  - held by crane4 until t_9
  - sits on p until t_{10} (or later)
- ship Uranus
  - stays at dock5 from t_{11} to t_{12}



Model

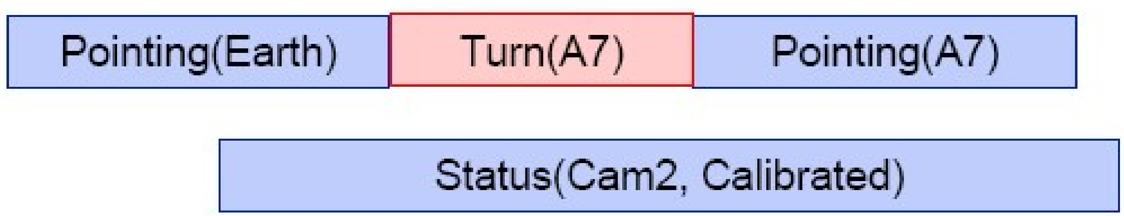
State-centric (Mc Carthy):

for each time describe propositions that are true



History-based (Hayes):

for each proposition describe times it is true



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Temporal Interval Relations

A before B

A meets B

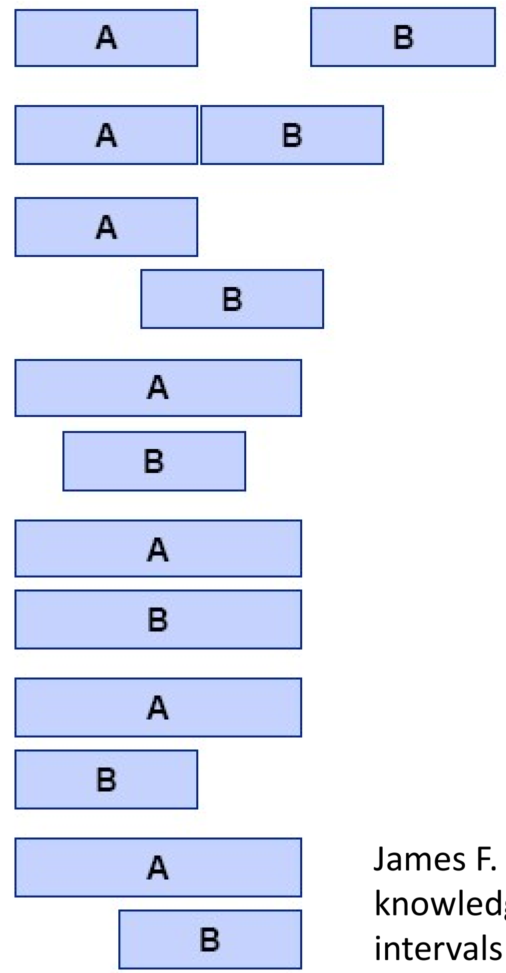
A overlaps B

A contains B

A = B

A starts B

A ends B



James F. Allen, "Maintaining knowledge about temporal intervals 1983

Based on slides by Dave Smith, NASA Ames

Temporal Operators

TakeImage (?target, ?instr):
    Pre: Status(?instr, Calibrated), Pointing(?target)
    Eff: Image(?target)

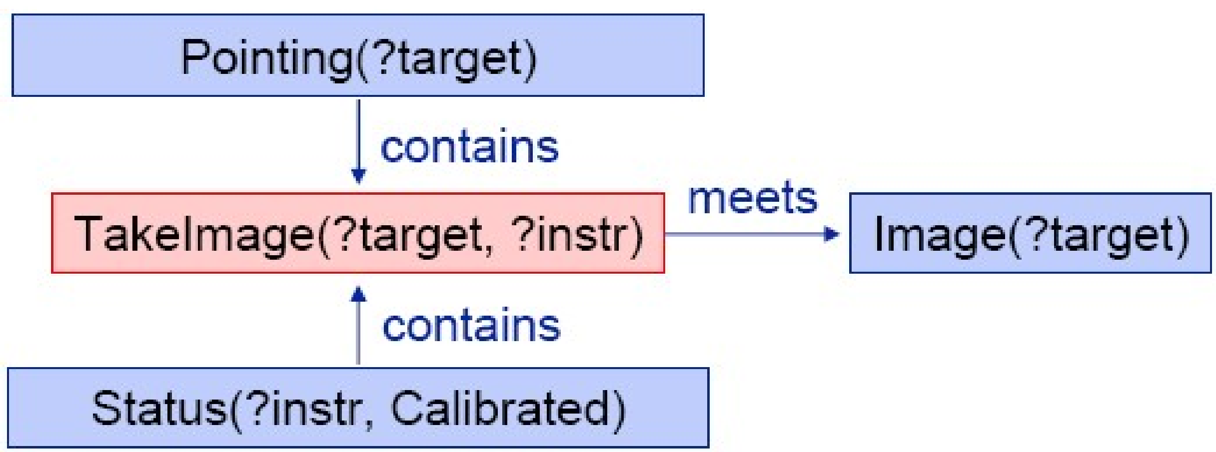
↓

TakeImage (?target, ?instr)	
contained-by	Status(?instr, Calibrated)
contained-by	Pointing(?target)
meets	Image(?target)

Based on slides by Dave Smith, NASA Ames

Temporal Operators

TakeImage (?target, ?instr)		
	contained-by	Status(?instr, Calibrated)
	contained-by	Pointing(?target)
	meets	Image(?target)



Based on slides by Dave Smith, NASA Ames

Temporal Operators

TakeImage (?target, ?instr)

contained-by	Status(?instr, Calibrated)
contained-by	Pointing(?target)
meets	Image(?target)

↓

$TakeImage(?target, ?instr)_A$

$\Rightarrow \exists P \{Status(?instr, Calibrated)_P \wedge Contains(P, A)\}$

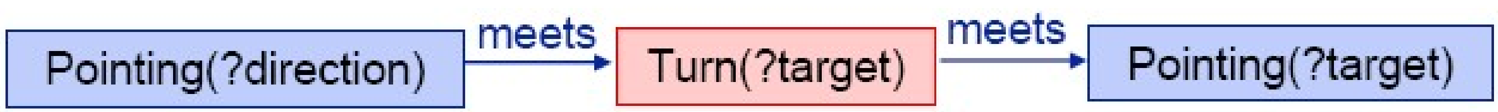
$\wedge \exists Q \{Pointing(?target)_Q \wedge Contains(Q, A)\}$

$\wedge \exists R \{Image(?target)_R \wedge Meets(A, R)\}$

Based on slides by Dave Smith, NASA Ames

Temporal Operators

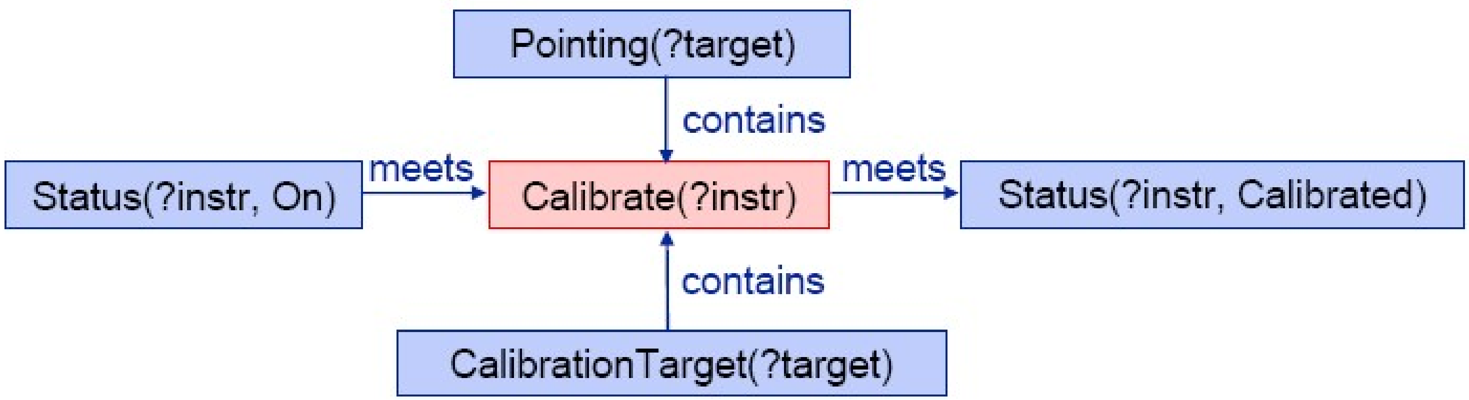
Turn (?target)
    met-by Pointing(?direction)
    meets Pointing(?target)



Temporal Operators

Calibrate (?instr)

met-by	Status(?instr, On)
contained-by	CalibrationTarget(?target)
contained-by	Pointing(?target)
meets	Status(?instr, Calibrated)



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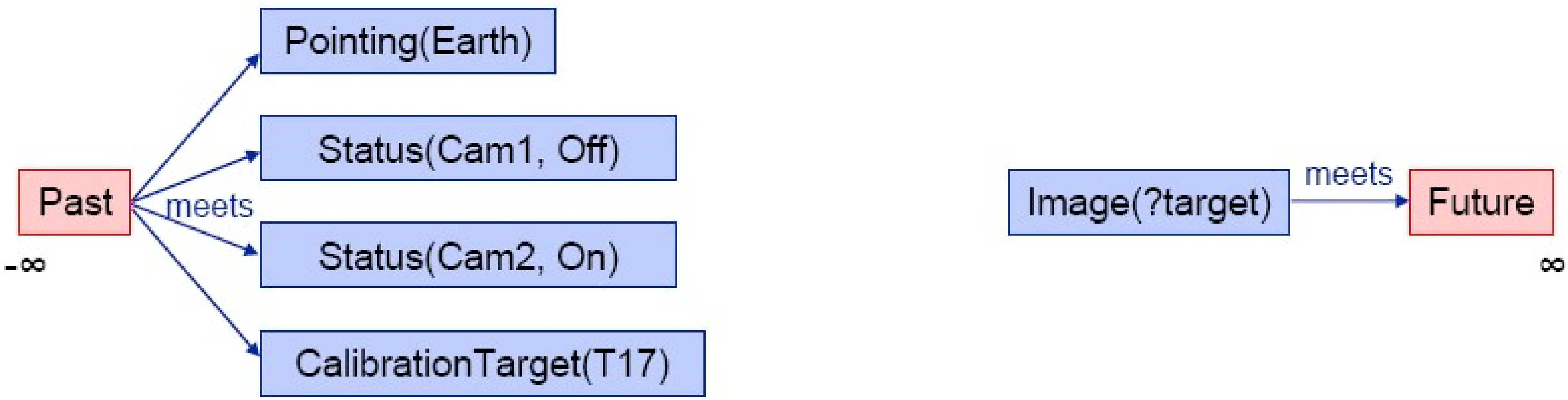
Temporal Planning Problem



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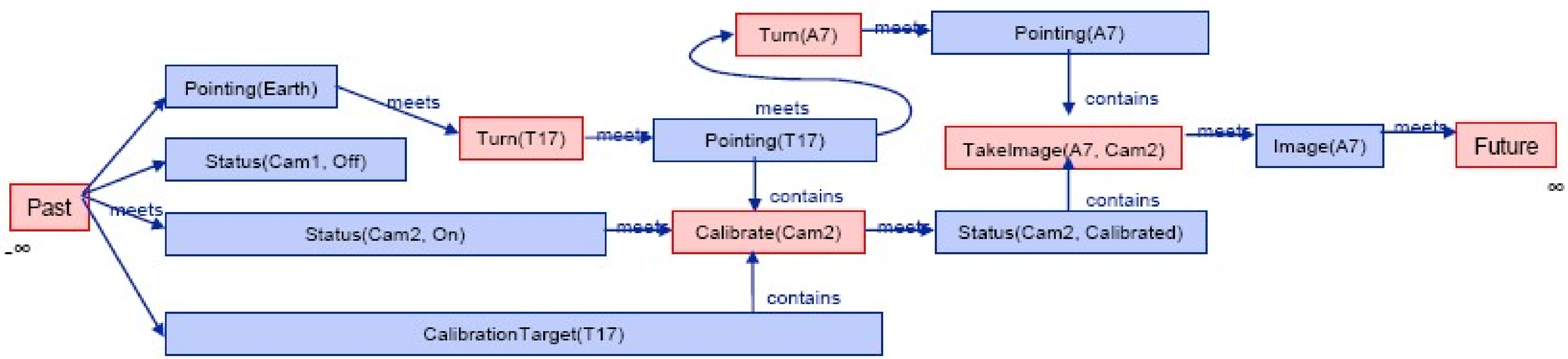
Consistent Complete Plan



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CBI-Planning

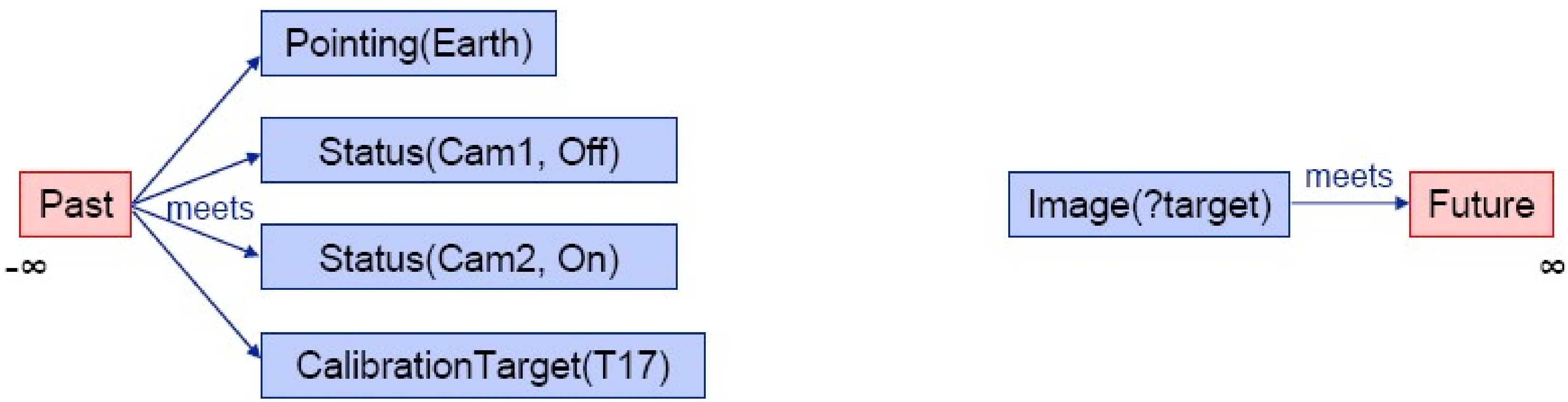
Choose:

introduce an action & instantiate constraints

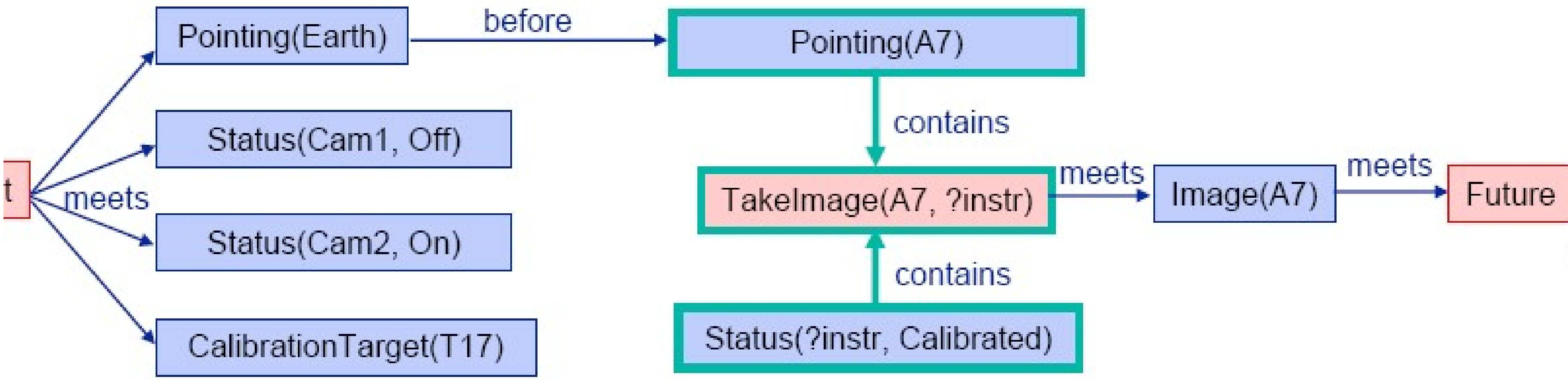
coalesce propositions

Propagate constraints

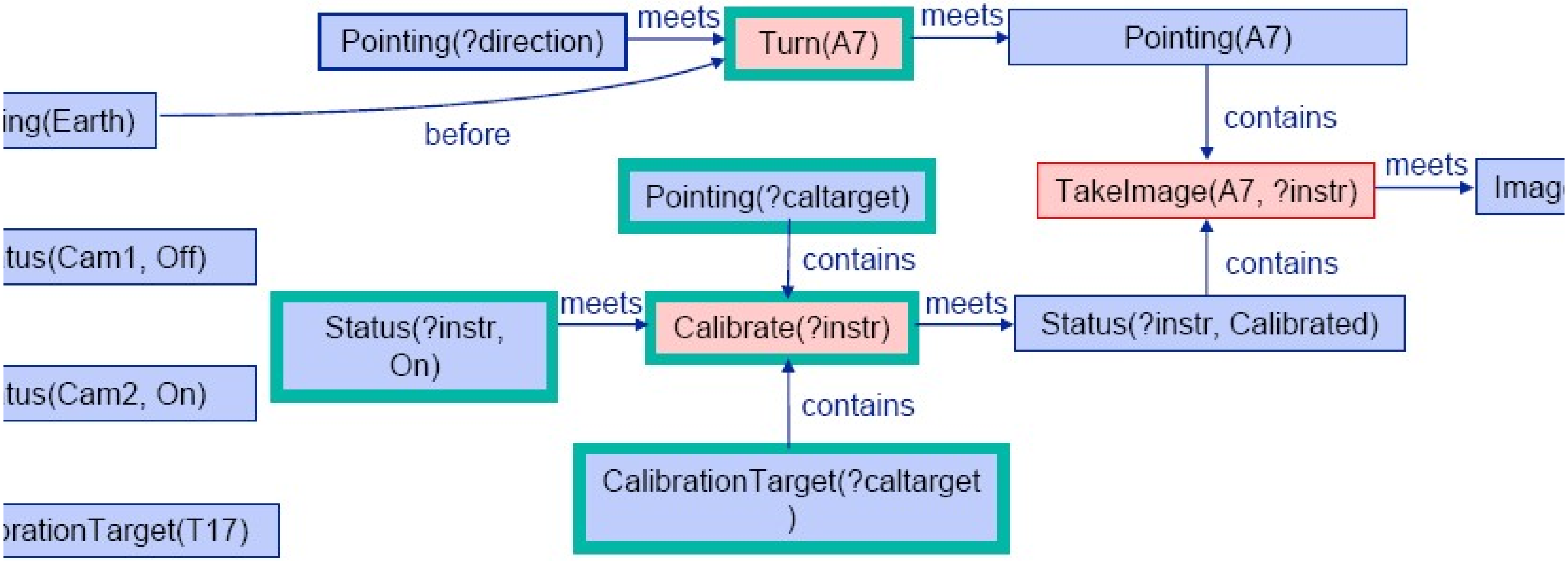
Initial Plan



Expansion

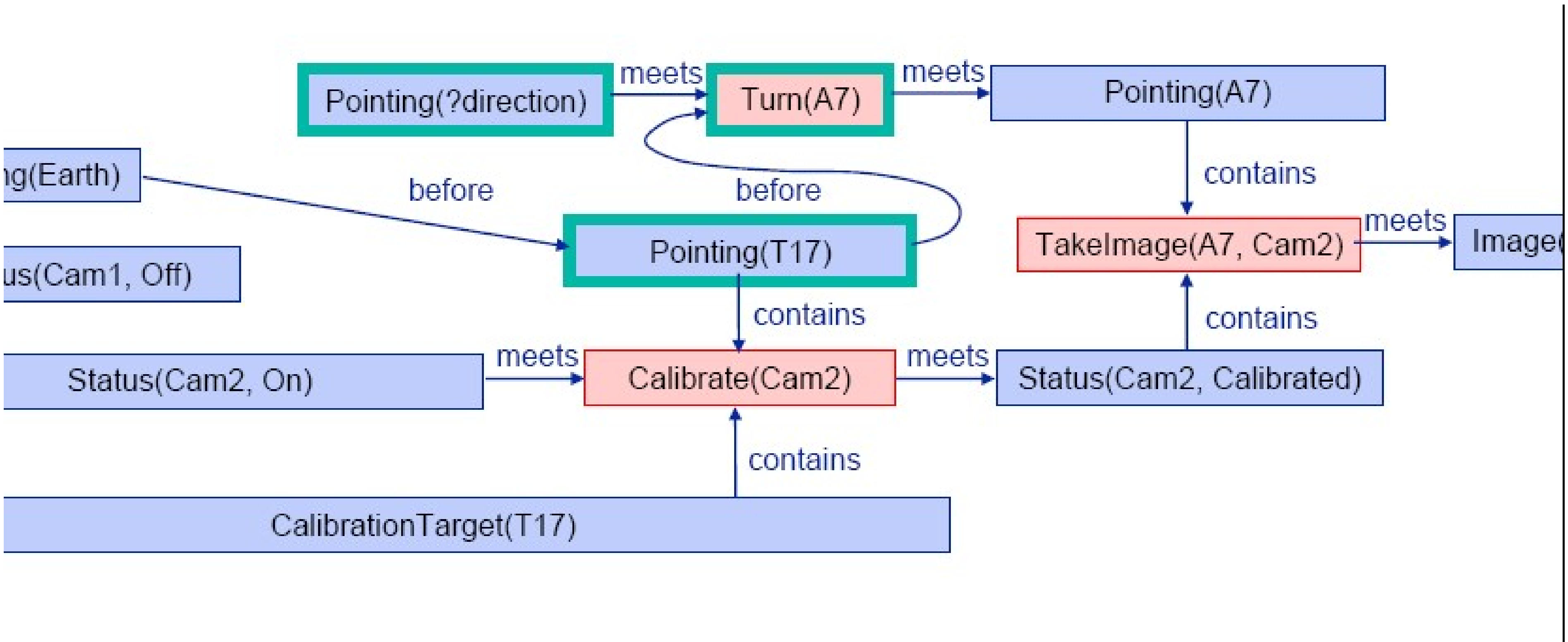

t
meets
Pointing(Earth)
before
Pointing(A7)
Status(Cam1, Off)
contains
Status(Cam2, On)
TakeImage(A7, ?instr)
meets
Image(A7)
meets
Future
contains
CalibrationTarget(T17)
Status(?instr, Calibrated)

Expansion



Based on slides by Dave Smith, NASA Ames

Coalescing



Pointing(?direction)
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Turn(A7)
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ng(Earth)
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us(Cam1, Off)
Pointing(T17)
TakeImage(A7, Cam2)
meets
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contains
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Status(Cam2, On)
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Calibrate(Cam2)
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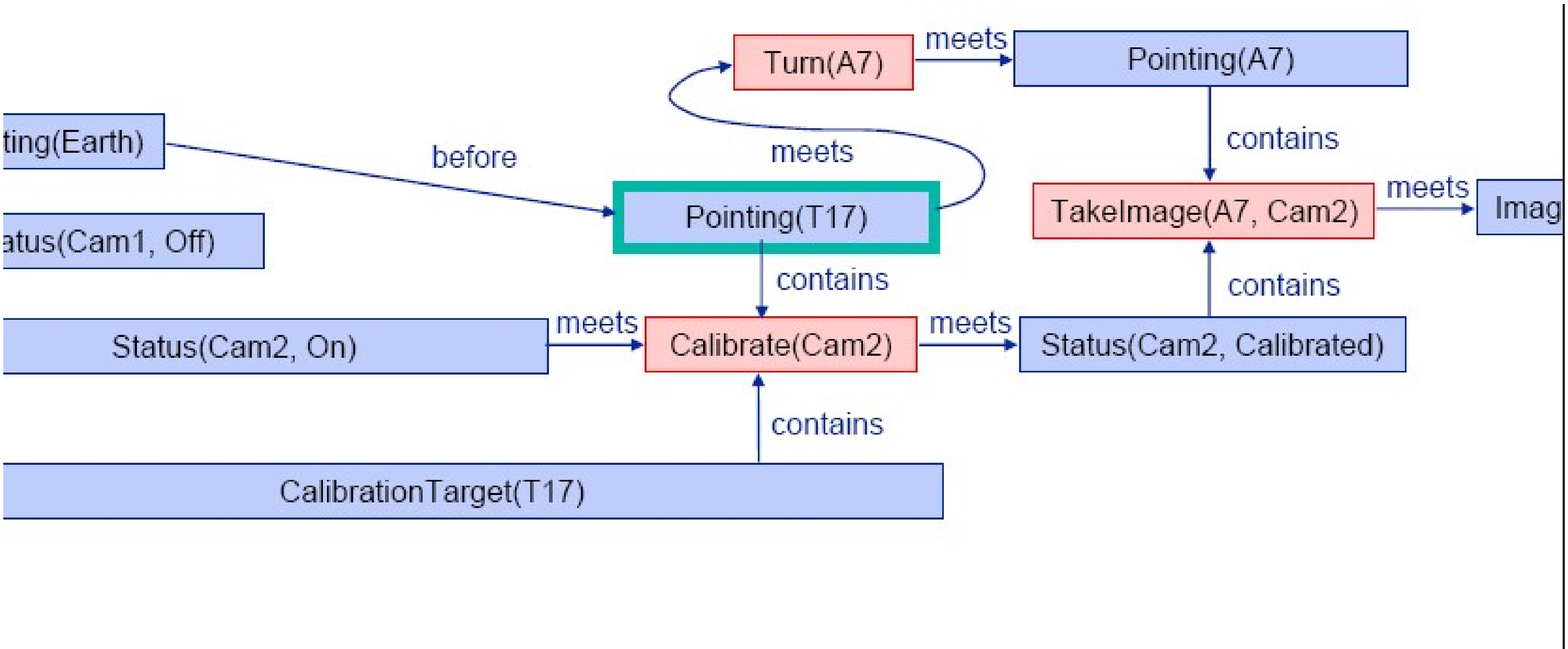
Status(Cam2, Calibrated)
contains
CalibrationTarget(T17)

Coalescing



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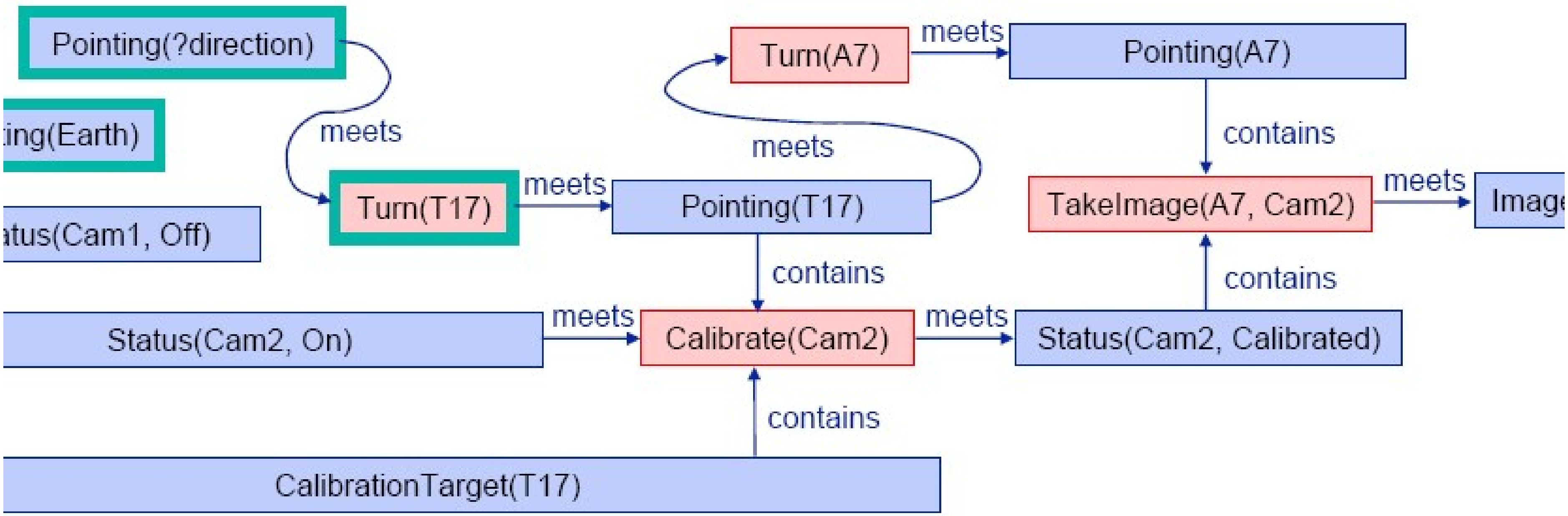
Expansion



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Pointing(T17)
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Turn(A7)
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TakeImage(A7, Cam2)
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Image
contains
Status(Cam2, On)
meets
Calibrate(Cam2)
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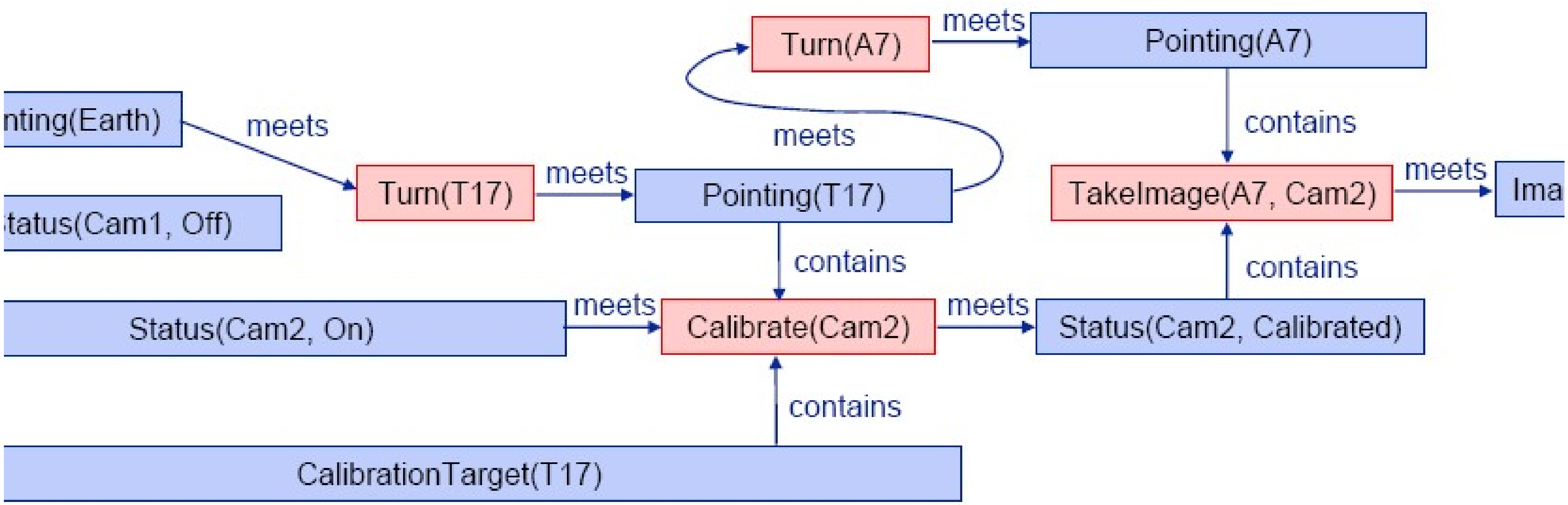
Status(Cam2, Calibrated)
contains
contains
CalibrationTarget(T17)

Coalescing



Turn(A7)
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contains
Status(Cam2, On)
meets
Calibrate(Cam2)
meets
Status(Cam2, Calibrated)
contains
CalibrationTarget(T17)

CBI-Algorithm

Expand(TQAs, constraints)

1. If the constraints are inconsistent, **fail**
2. If all TQAs have causal explanations, **return**(TQAs, constraints)
3. Select a $g \in$ TQAs with no causal explanation
4. **Choose**:

    Choose another $p \in$ TQAs such that g can be coalesced with p under constraints C

        Expand(TQAs-g, constraints $\cup$ C)

    Choose an action that would provide a causal explanation for g

        Let A be a new TQA for the action,
        and let R be the set of new TQAs implied by the axioms for A

        Let C be the constraints between A and R

        Expand(TQAs $\cup$ {A} $\cup$ R, constraints $\cup$ C)

CBI-Planners

Zeno (Penberthy)	intervals, no CSP
Trains (Allen)	
Descartes (Joslin)	extreme least commitment
IxTeT (Ghallab)	functional rep.
HSTS (Muscettola)	functional rep., activities
EUROPA (Jonsson)	functional rep., activities

CBI vs POP

- CBI is similar to POP because least commitment and partial order
- But, temporal constraints in CBI …
- Contraints Temporal Network associated with a plan
- Constraint propagation

Temporal Assertions

- Temporal assertion:
  - *Event*: an expression of the form $x@t : (v_1,v_2)$
    - » At time t, x changes from v_1 to $v_2 \neq v_1$
  - *Persistence condition*: $x@[t_1,t_2) : v$
    - » $x = v$ throughout the interval $[t_1,t_2)$
  - where
    - » t, t_1, t_2 are constants or temporal variables
    - » v, v_1, v_2 are constants or object variables
- Note that the time intervals are semi-open
  - Why?
  - To prevent potential confusion about x's value at the endpoints

Chronicles

- *Chronicle*: a pair $\Phi = (F, C)$
  - F is a finite set of temporal assertions
  - C is a finite set of constraints
    - » temporal constraints and object constraints
  - C must be consistent
    - » i.e., there must exist variable assignments that satisfy it
- *Timeline*: a chronicle for a single state variable

Chronicles as Planning Operators

- Chronicle planning operator: a pair o = (name(o), ($F(o)$,$C(o)$)), where
  - name(o) is an expression of the form $o(t_s, t_e, \ldots, v_1, v_2, \ldots)$
    - » o is an operator symbol
    - » $t_s, t_e, \ldots, v_1, v_2, \ldots$ are all the temporal and object variables in o
  - ($F(o)$, $C(o)$) is a chronicle

Domains and Problems

- Temporal planning *domain*:
  - A pair $\boldsymbol{D} = (\Lambda_\Phi, O)$
    - » O = {all chronicle planning operators in the domain}
    - » Λ_Φ = {all chronicles allowed in the domain}
- Temporal planning *problem* on $\boldsymbol{D}$:
  - A triple $\boldsymbol{P} = (\boldsymbol{D}, \Phi_0, \Phi_g)$
    - » $\boldsymbol{D}$ is the domain
    - » Φ_0 and Φ_g are initial chronicle and goal chronicle
    - » O is the set of chronicle planning operators
- Statement of the problem $\boldsymbol{P}$:
  - A triple $P = (O, \Phi_{0,} \Phi_g)$
    - » O is the set of chronicle planning operators
    - » Φ_0 and Φ_g are initial chronicle and goal chronicle
- *Solution plan*:
  - A set of actions $\pi = \{a_1, \ldots, a_n\}$ such that at least one chronicle in $\gamma(\Phi_0, \pi)$ entails Φ_g

Planning & Scheduling