The Productions of Time

Mark Steedman, Informatics, University of Edinburgh

Summer School in Behavioural and Cognitive Neurosciences

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Eternity is in love with the productions of time

— William Blake, *The Marriage of Heaven and Hell*.

`www.cogsci.ed.ac.uk/~steedman/papers.html`

TEMPORAL ONTOLOGY: Phenomena and Frameworks

The Perfect

- Tenses/Aspects aren't primarily to do with time at all.

(1) I have lost my watch (# but I have found it again)

(2) Yesterday, I lost my watch (but I (have) found it again)

(3) a. #I have breathed
    b. #Einstein has visited New York

The Progressive

- Tenses/Aspects are non-uniform with respect to factive entailment:

  (4) a. Keats was writing $\models$ Keats wrote
  b. Keats was writing a sonnet $\not\models$ Keats wrote a sonnet

  (5) A proposition ϕ holding of an interval *t* is downward entailing if it entails that ϕ also holds of all subintervals of *t* down to some reasonable minimum size.

- Hence we must establish an ontology of *types* of events.

- A standard move in natural language semantics.

Vendler 1967

- Achievements:

(6) a. Keats finished the sonnet in fifteen minutes.
b. #Keats finished the sonnet for fifteen minutes.
c. Keats is finishing the sonnet ($\not\models$ Keats will have finished the sonnet).
d. Keats has finished the sonnet.

- Activities:

(7) a. Keats wrote for fifteen minutes.
b. #Keats wrote in fifteen minutes.
c. Keats is writing ($\models$ Keats will have written).
d. #Keats has written.

Vendler 1967 (contd.)

- Accomplishments:

  (8) a. Keats wrote *In Disgust of Vulgar Superstition* in fifteen minutes.
  b. #Keats wrote the sonnet for fifteen minutes.
  c. Keats is writing the sonnet ($\not\models$ Keats will have written the sonnet).
  d. Keats has written the sonnet

- States:

  (9) a. Keats is a genius.
  b. Keats is looking into Chapman's Homer.
  c. I have lost my watch.
  d. I work for the union.

Aspectual Coercion

- Aspect is not inherent in verbs.
- Suppose we know that Keats writes a sonnet to time every Sunday afternoon, and that on 23rd of December 1816 he did it in just fifteen minutes. We can say:

  (10) Keats wrote in fifteen minutes.

Aspectual Coercion (contd.)

- Iteration

(11) Chapman sliced the onion (into rings)

(12) I am slicing the onions

(13) I am writing a sonnet in fifteen minutes (these days).

(14) a. # Chapman arrived all night.
b. Visitors arrived all night.

(15) It took me two years to play the "Minute Waltz" in less than sixty seconds for one hour without stopping.

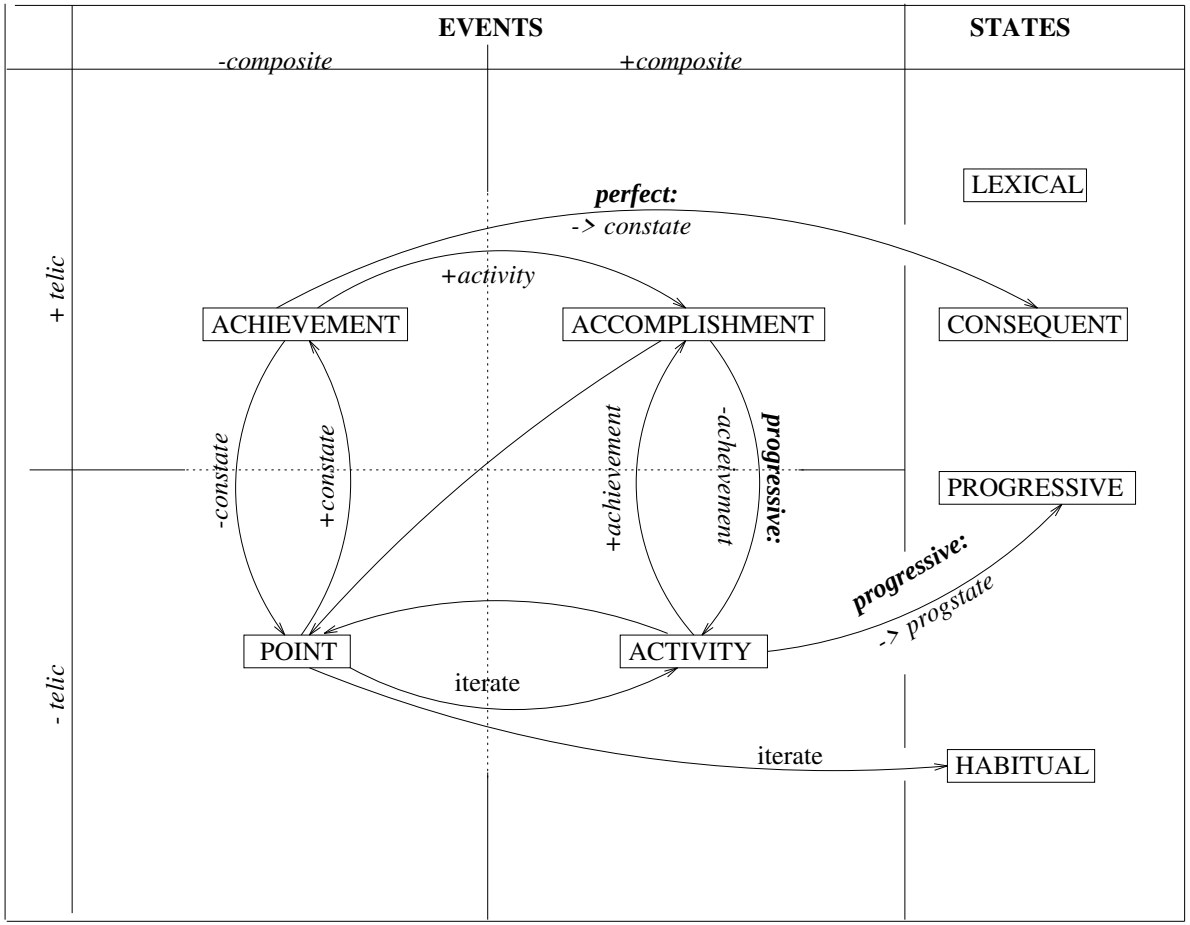


Figure 1: A scheme of aspectual coercion (Moens and Steedman 1988)

The Nuclear Structure of Default Temporal Relations

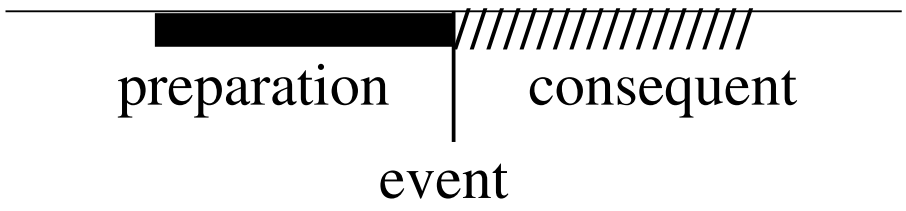


Figure 2: The event nucleus (adapted from Moens and Steedman 1988)

This structure, or "nucleus" can be regarded as composed of the types described in figure 1. Thus the preparation is an activity, the consequent is the same kind of state that the perfect gives rise to, while the event itself is an achievement.

TEMPORAL ONTOLOGY: Logic and Computation

- Coercions as Rules: the effect of the progressive:

(16) a. $\models in_progress(act) \rightarrow progressive(activity(act))$

b. $\models preparation(act, ach) \wedge progressive(activity(act))$
$\rightarrow progressive(accomplishment(activity(act), achievement(ach)))$

c. $\models preparation(act, ach)$
$\wedge progressive(accomplishment(activity(act), achievement(ach)))$
$\rightarrow progressive(achievement(ach))$

- To prove:

(17) $progressive(achievement(complete(keats, in_disgust)))$

- Assume the preparation for completing a sonnet is just writing it:

  (18) $\models sonnet(y)$
  $\rightarrow preparation(activity(write(x,y)), achievement(complete(x,y)))$

- Axioms (16) allows us to set up successive subgoals"

  (19) $progressive(accomplishment(activity(write(x, in_disgust)),$
  $achievement(complete(x, in_disgust))))$

  (20) $progressive(activity(write(x, in_disgust)))$

  (21) $in_progress(write(x, in_disgust))$

Coercive Verbs: Thomason 1999

- Keats tried to write a sonnet.

  (22) $\models preparation(act, ach) \wedge intend(ach) \wedge do(act)$
  $\rightarrow try(accomplishment(activity(act), achievement(ach)))$

- Keats failed to write a sonnet

  (23) $\models preparation(act, ach) \wedge failed(ach) \wedge intend(ach) \wedge do(act)$
  $\rightarrow fail(accomplishment(activity(act), achievement(ach)))$

- Keats trousered the £5 note.

  (24) $\models normalstate(x, trousers, s) \wedge constate(achievement(ach), s)$
  $\wedge preparation(act, ach)$
  $\wedge do(accomplishment(activity(act), achievement(ach)))$
  $\rightarrow trouser(x)$

TEMPORAL RELATIONS: Phenomena and Frameworks

- Reichenbach 1947:

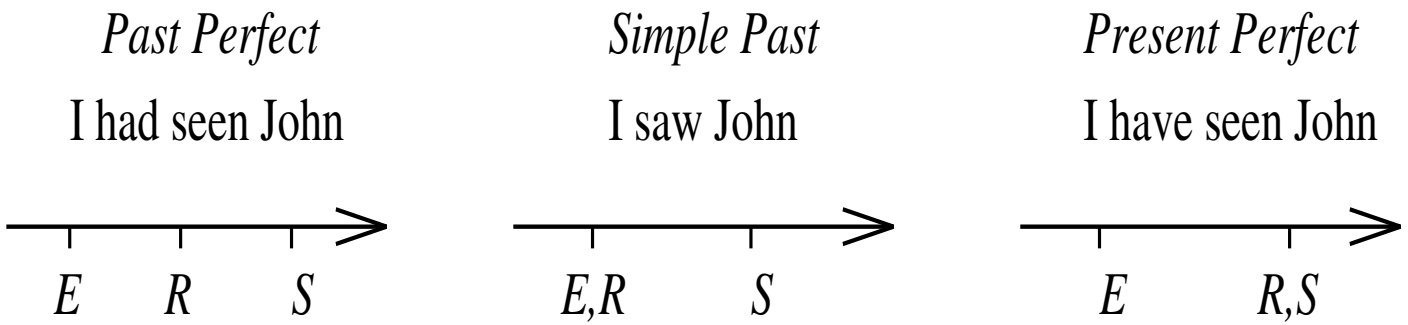


Figure 3: Past vs. Perfect (from Reichenbach 1947)

- "Positional use of R(eference point)" (see next chapter)

(25) a. #Chapman breathed a sigh of relief

b. When Nixon was elected, Chapman breathed a sigh of relief

(26) a. In ten minutes, I looked at my watch.
b. When Chapman arrived, the band was playing *Nice Work If You Can Get It*.
c. After Einstein arrived in Princeton, he may have visited Philadelphia.

(27) I had arrived in Vermilion Sands three months earlier. A retired pilot, I was painfully coming to terms with a broken leg and the prospect of never flying again. . . .

(28) a. Chapman said that he had arrived in Vermillion Sands three months earlier.
b. Chapman said that he was painfully coming to terms with a broken leg.

(29) a. #Harry moves to Philadelphia.
b. Next Tuesday, Harry moves to Philadelphia.

Reichenbach Extended

Simple Past

I gave a lecture

Present

I name this ship the *Prime Directive*

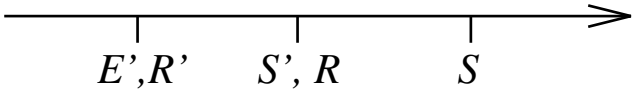
Simple Future

I give a lecture (next Tuesday)

Figure 4: The tenses for composite events

Narrative Pluperfect

I had arrived in Vermilion Sands (three weeks earlier)



Narrative Past

I was coming to terms with a broken leg (E')

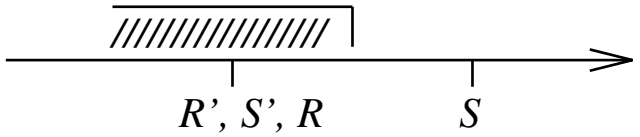


Figure 5: The narrative tenses

Past Counterfactual

If I had won (I would now be rich)

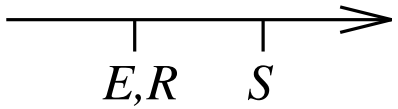


Figure 6: The counterfactual pluperfect

The Perfect and the Progressives

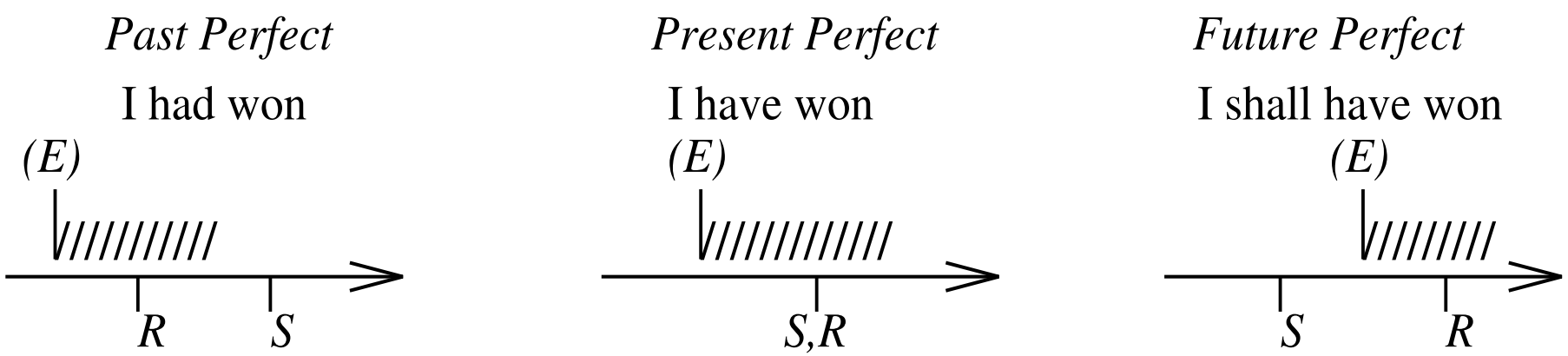


Figure 7: The perfect

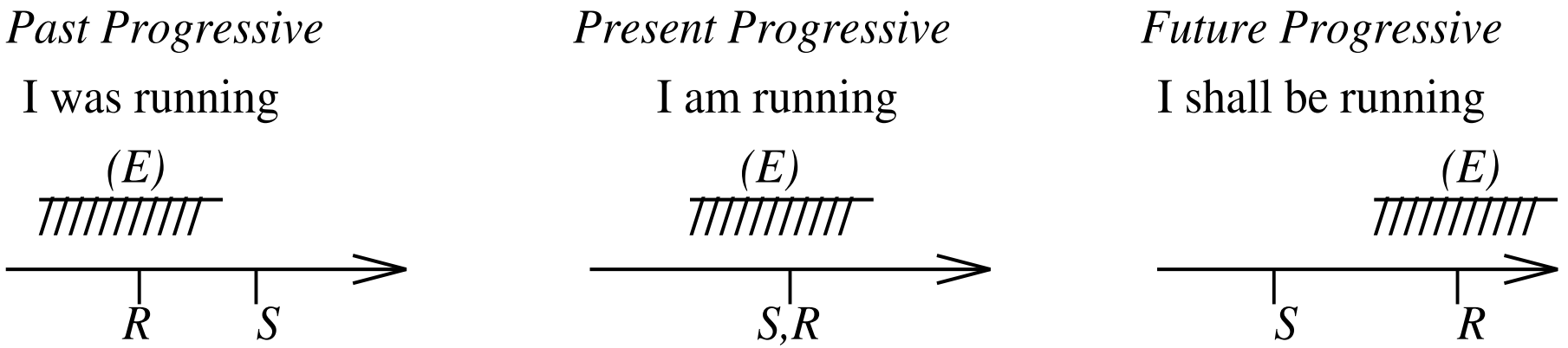


Figure 8: The progressive

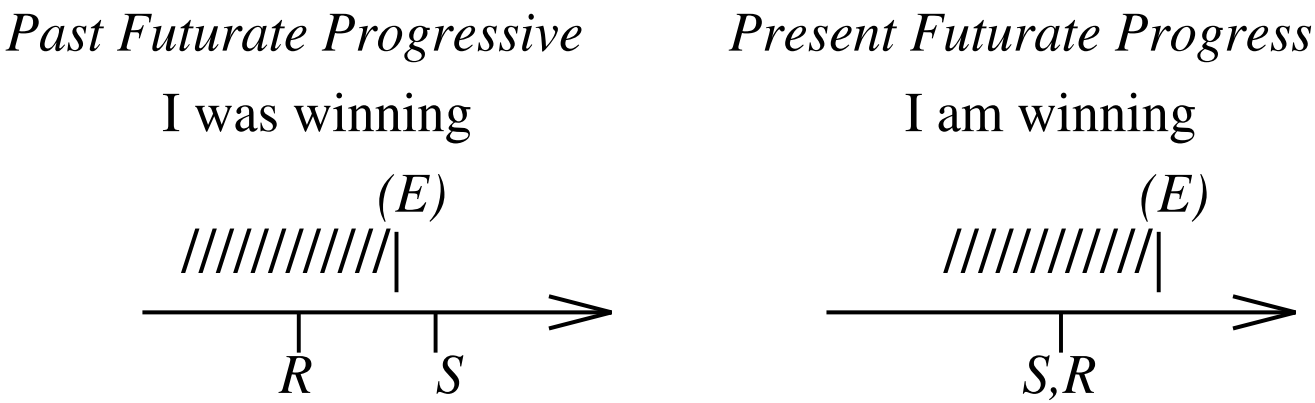


Figure 9: The futurate progressives

Kripke Model

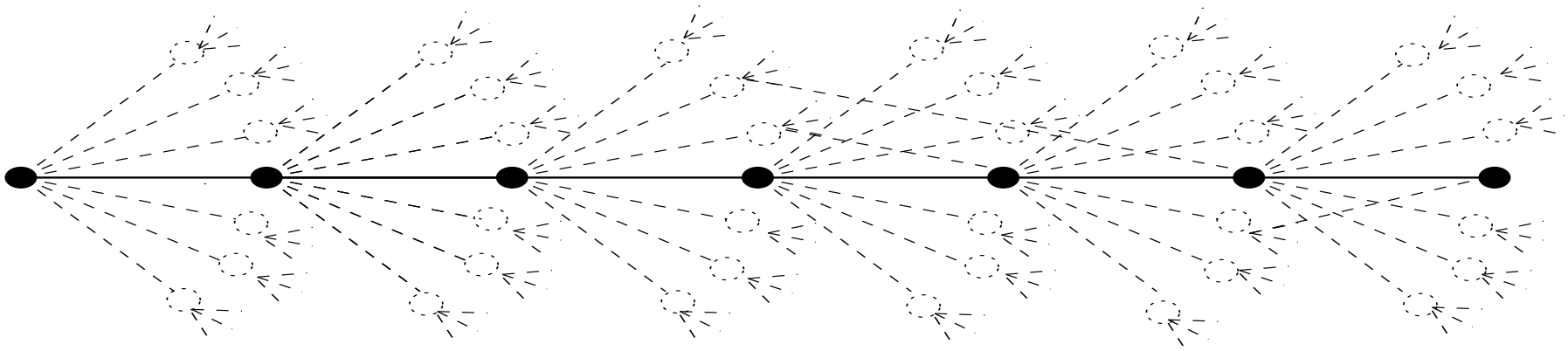


Figure 10: Modal Temporal Structure

- Counterfactuals:

  (30) If you had taken my queen, you would have won the game.

  (31) If Nixon had pushed the button, there would have been a nuclear war.

TEMPORAL RELATIONS: Logic and Computation

- The Situation Calculus of McCarthy and Hayes

(32) $\forall s, \forall person, present(person, result(arrive(person), s))$

(33) a. $clear(a, s_0) \wedge clear(b, s_0) \wedge clear(c, s_0)$

b. $\forall x, \forall y, \forall s, clear(x, s) \wedge clear(y, s) \wedge x \neq y$
$\rightarrow clear(x, result(puton(x, y, s)))$
$\wedge \neg clear(y, result(puton(x, y, s)))$
$\wedge on(x, y, result(puton(x, y, s)))$

(34) $on(a, b, result(puton(a, b, result(puton(b, c, s_0)))))$
$\wedge on(b, c, result(puton(a, b, result(puton(b, c, s_0)))))$

(35) a. $\forall u, \forall x, \forall y, \forall s, clear(u, s) \wedge u \neq y \rightarrow clear(u, result(puton(x, y, s)))$

b. $\forall u, \forall v, \forall x, \forall y, \forall s, on(u, v, s) \wedge u \neq x \rightarrow on(u, v, result(puton(x, y, s)))$

A Declarative Solution to the Frame Problem (Kowalski)

The situation:

(36) $holds(clear(a), s_0) \wedge holds(clear(b), s_0) \wedge holds(clear(c), s_0)$

Preconditions of *puton*

(37) $holds(clear(x), s) \wedge holds(clear(y), s) \wedge (x \neq y)$
$\rightarrow preconditions(puton(x, y), s)$

Consequences of *puton*

(38) a. $holds(on(x, z), s) \rightarrow holds(clear(z), result(puton(x, y), s))$
b. $holds(on(x, y), result(puton(x, y), s))$

"Frame Axiom" for *puton*

(39) $holds(p,s) \wedge (p \neq clear(y)) \wedge (p \neq on(x,z))$
$\rightarrow holds(p, result(puton(x,y),s))$

(40) a. $poss(s_0)$
b. $poss(s) \wedge preconditions(action,s) \rightarrow poss(result(action,s))$

(41) $poss(s) \wedge holds(on(a,b),s) \wedge holds(on(b,c),s)$

(42) $s = result(puton(a,b), result(puton(b,c),s_0))$

Counterfactuals

(43) If Nixon had pushed the button, there would have been a nuclear war.

The Dynamic Event Calculus

Dynamic Logic:

(44) $n \geq 0 \rightarrow [\alpha](y = F(n))$

(45) $n \geq 0 \rightarrow \langle\alpha\rangle(y = F(n))$

Sequential Composition:

(46) $[\alpha][\beta]P \rightarrow [\alpha;\beta]P$

Notation: Situation Calculus vs. Dynamic Event Calculus

(47) a. $holds((on(a,b) \wedge on(b,c)), result(puton(a,b), result(puton(b,c), s_0)))$

b. $[puton(b,c);puton(a,b)](on(a,b) \wedge on(b,c))$

Frame Problem Revisited

The start state:

(48) $clear(a) \wedge clear(b) \wedge clear(c)$

Preconditions of *puton*

(49) $\models clear(x) \wedge clear(y) \wedge (x \neq y) \rightarrow possible(puton(x,y))$

Consequences of *puton*

(50) a. $\models on(x,z) \rightarrow [puton(x,y)]clear(z)$
b. $\models [puton(x,y)]on(x,y)$

Frame Axiom for *puton*

(51) $\models p \wedge (p \neq clear(y)) \wedge (p \neq on(x,z)) \rightarrow [puton(x,y)]p$

Composition:

(52) $\models possible(\alpha) \wedge [\alpha] possible(\beta) \rightarrow possible(\alpha;\beta)$

Goal to find a plan to put a on b on c:

(53) $possible(\alpha) \wedge [\alpha](on(a,b) \wedge on(b,c))$

The plan:

(54) $\alpha = puton(b,c);puton(a,b)$

Durative Events in DEC

(55) a. $\models [start(p)]in_progress(p)$

b. $\models \neg in_progress(move(x, l_0, l)) \wedge at(x, l_0)$
$\rightarrow possible(start(move(x, l_0, l)))$

c. $\models p \wedge p \neq at(x, l_0) \rightarrow [start(move(x, l_0, l))]p$

d. $\models [stop(move(x, l_0, l))]at(x, l)$

(56) $\models in_progress(p) \rightarrow possible(stop(p))$

(57) $\models p \wedge (p \neq in_progress(q)) \rightarrow [stop(q)]p$

The Auchterarder Pizza Delivery Scenario

(58) a. $possible(\alpha) \wedge [\alpha]at(car, Auchterarder)$

b. $\alpha = [start(move(car_1, Edinburgh, Auchterarder));$
$stop(move(car_1, Edinburgh, Auchterarder))$

(59) $\models in(x,y) \wedge at(y,l) \rightarrow at(x,l)$

(60) a. $possible(\alpha) \wedge [\alpha]at(pizza, Auchterarder)$

b. $\alpha = [start(move(car_1, Edinburgh, Auchterarder));$
$stop(move(car_1, Edinburgh, Auchterarder))$

(61) $\models p \wedge (p \neq in(x,y)) \rightarrow [eject(x,y)]p$

(62) $\alpha = [start(move(car_1, Edinburgh, Auchterarder)); eject(pizza, car);$
$stop(move(car_1, Edinburgh, Auchterarder))$

The Progressive Again

(63) a. $\models in_progress(act) \rightarrow progressive(activity(act))$

b. $\models preparation(act, ach) \wedge progressive(activity(act))$
$\rightarrow progressive(accomplishment(activity(act), achievement(ach)))$

c. $\models preparation(act, ach)$
$\wedge progressive(accomplishment(activity(act), achievement(ach)))$
$\rightarrow progressive(achievement(ach))$

The Imperfective Paradox

(64) $possible(\alpha) \wedge [\alpha] progressive(achievement(complete(keats, in_disgust)))$

(65) $\models sonnet(y) \rightarrow preparation(activity(write(x,y)), achievement(complete(x,y)))$

(66) $\alpha = start(write(keats, in_disgust))$

Cause and Contingency in Dynamic Event Calculus

(67) a. $\models [arrive(x)]present(x)$

b. $\models not(present(x)) \rightarrow possible(arrive(x))$

c. $\models p \rightarrow [arrive(x)]p$

(68) $\alpha = start(write(keats, in_disgust))$

$\alpha = start(write(keats, in_disgust)); arrive(chapman)$

$\alpha = start(write(keats, in_disgust)); arrive(chapman); arrive(homer)$

$\ldots$

(69) $\alpha = start(write(keats, sonnet)); arrive(x); stop(write(keats, sonnet)$

Cause and Contingency (Contd.)

(70) $\models (possible(\alpha) \wedge [\alpha]necessary(\beta)) \rightarrow possible(\alpha@\beta)$

(71) $\models present(x) \wedge (x \neq keats) \wedge in_progress(write(keats, y))$
$\rightarrow necessary(stop(write(keats, y)))$

(72) a. $\alpha = start(write(keats, y)); arrive(x)$
b. $\alpha = start(write(keats, y))$

(73) $\models [flip]necessary(turnon)$

The (Solved) Ramification Problem

The consequences of an action may be overridden.
Start State (simplified by omitting the individual)

(74) $at(here) \wedge color(green)$

Frame axiom for *move* (similarly simplified):

(75) $\models p \wedge p \neq at(a) \rightarrow [start(move(a,b))]p$

consequences of spraying something a color d:

(76) $\models [start(spray(d))]color(d)$

Frame axiom for spraying something a color d:

(77) $\models p \wedge p \neq color(c) \wedge c \neq d \rightarrow [start(spray(d))]p$

Then we correctly fail to prove the following:

(78) $[start(move(here, there)); start(spray(pink));$
$stop(spray(pink)); stop(move(here, there))]color(green)$

(79) $[start(spray(pink)); start(move(here, there));$
$stop(move(here, there)); stop(spray(pink))]at(here)$

Clock-time

Its easy enough to fix up DEC with temporal indices identifying clock times:

(80) $[_0 start(move(here, there))_1; start(spray(pink))_1;$
$stop(spray(pink))_2; stop(move(here, there))_2]_2 color(green)$

(81) $[_0 start(spray(pink))_1; start(move(here, there))_1;$
$stop(move(here, there))_2; stop(spray(pink))_2]_2 at(here)$

"Generation" (Goldman)

(82) $\models [_t flip]_t necessary(turnon_t)$

(83) $\models [_{t_0} \alpha]_{t_2} clocktime(t_2)$

Delayed Action

(84) a. $\models alive \rightarrow possible(die)$

b. $\models [die]\neg alive$

c. $\models p \wedge \neg(p = alive) \rightarrow [die]p$

(85) $\models [_{t_0} drink(A_s)_{t_1}]_{t_2} constate(drink(A_s)_{t_1})$

(86) $\models constate(drink(A_s)_{t_1}) \wedge clocktime(t_2) \wedge t_2 = (t1 + 4)$
$\rightarrow necessary(die_{t_2})$

(87) $possible(\alpha) \wedge [\alpha] necessary(die)$

(88) $[_0 drink - A_{s_0}]_4 \neg alive$

TEMPORAL REFERENCE: Phenomena and Frameworks

(89) a. When I took your pawn, you took my queen.
b. I took your pawn. You took my queen

(90) When I took your pawn, I did not know it was protected by your knight.

(91) When I took your pawn, I used a rook.

(92) a. If you take my queen, you may win.
b. If you had taken my queen, you might have won.
c. Since you took my queen, you have been winning.

TEMPORAL REFERENCE: Logic and Computation

In Dynamic Event Calculus:

(93) $start(write(keats, in_disgust)); arrive(chapman)$
$@stop(write(keats, in_disgust)$

(94) $start(write(keats, in_disgust)); arrive(chapman)$

(95) a. $\models evoke((\alpha;\beta),(\alpha;\beta))$
b. $\models evoke((\alpha;\beta),\gamma) \rightarrow evoke((\alpha;\beta),(\gamma;\delta))$

(96) a. $\models state(\gamma) \wedge S(history) \wedge evoke((\alpha;\beta), history) \wedge [\alpha;\beta]\gamma$
$\rightarrow when(\beta,\gamma)$
b. $\models event(\varepsilon) \wedge S(history) \wedge evoke((\alpha;\beta@\varepsilon), history) \rightarrow when(\beta,\varepsilon)$

(97) a. When Chapman arrived, was Keats completing *In Disgust of Vulgar Superstition*?

b. $when((\alpha; arrive(chapman)),$
$progressive(achievement(complete(keats, in_disgust))))$

(98) a. When Chapman arrived, did Keats stop writing *In Disgust of Vulgar Superstition*?

b. $when((\alpha; arrive(chapman)), stop(write(keats, in_disgust)))$

(99) $when((start(write(keats, in_disgust)); arrive(chapman)),$
$stop(write(keats, in_disgust)))$

(100) a. #When Keats started writing *In Disgust of Vulgar Superstition*, Chapman arrived.

b. Keats started writing *In Disgust of Vulgar Superstition*. Chapman arrived.

(101) a. When Chapman arrived, Keats stopped writing.

b. When Chapman flipped the switch, he turned on the light.

The (Unsolved) Qualification Problem

You can never state all the conditions of an action.

I am sitting in my car and I want to drive. I know that for me to drive the engine must be running, and that for it to be running I must switch it on and that the precondition for switching on is to have the key in the lock and the way to do that is to put it there, for which the only precondition is my being there.

There are several, possibly infinitely many, further preconditions. For example, if there is a potato on the tailpipe of a car, switching on will not result in the engine running. By assumption, this practical precondition is not explicit in the knowledge representation that I am using. What do I do?

either: Some hard scientific reasoning from first principles according to the Hypothetico Deductive Method.

or: Kick the tires.