



## **Another avenue to the event calculus: the perfective/imperfective dichotomy and nominalization**

- the ontology of the event calculus embodies the fundamental distinction between perfective and imperfective aspect:
- there is a formal distinction between event types and fluents
- Davidsonian approaches cannot capture this ...
- but it comes at the price of great logical complications: one needs a theory of truth

## Axioms for the event calculus: eventualities as objects

**Axiom' 1**  $Initially(f) \wedge \neg Clipped(0, f, t) \rightarrow HoldsAt(f, t)$

**Axiom' 2**  $Happens(e, t) \wedge Initiates(e, f, t) \wedge t < t' \wedge \neg Clipped(t, f, t') \rightarrow HoldsAt(f, t')$

**Axiom' 3**  $Happens(e, s) \wedge t < s < t' \wedge Terminates(e, f, s) \rightarrow Clipped(t, f, t')$

- why two kinds of eventualities?
- where do they come from?
- what is the role of *HoldsAt*?

## Eventualities as objects: cognition

- what *is* an event cognitively speaking? (Zacks/Tversky)
- ‘a segment of time at a given location that is conceived by an observer to have a beginning and an end’
- object :: space = event :: time
- hypothesis: *events stored in memory according to the same principles as objects*
- a common principle is hierarchical organization
- (and the analogue for goal-plan organization is *function* of an object)

## David Marr on hierarchical organization

Q. What do you feel are the most promising approaches to semantics?

A. Probably what I call the problem of multiple descriptions of objects and the problems of reference that multiple descriptions introduce:

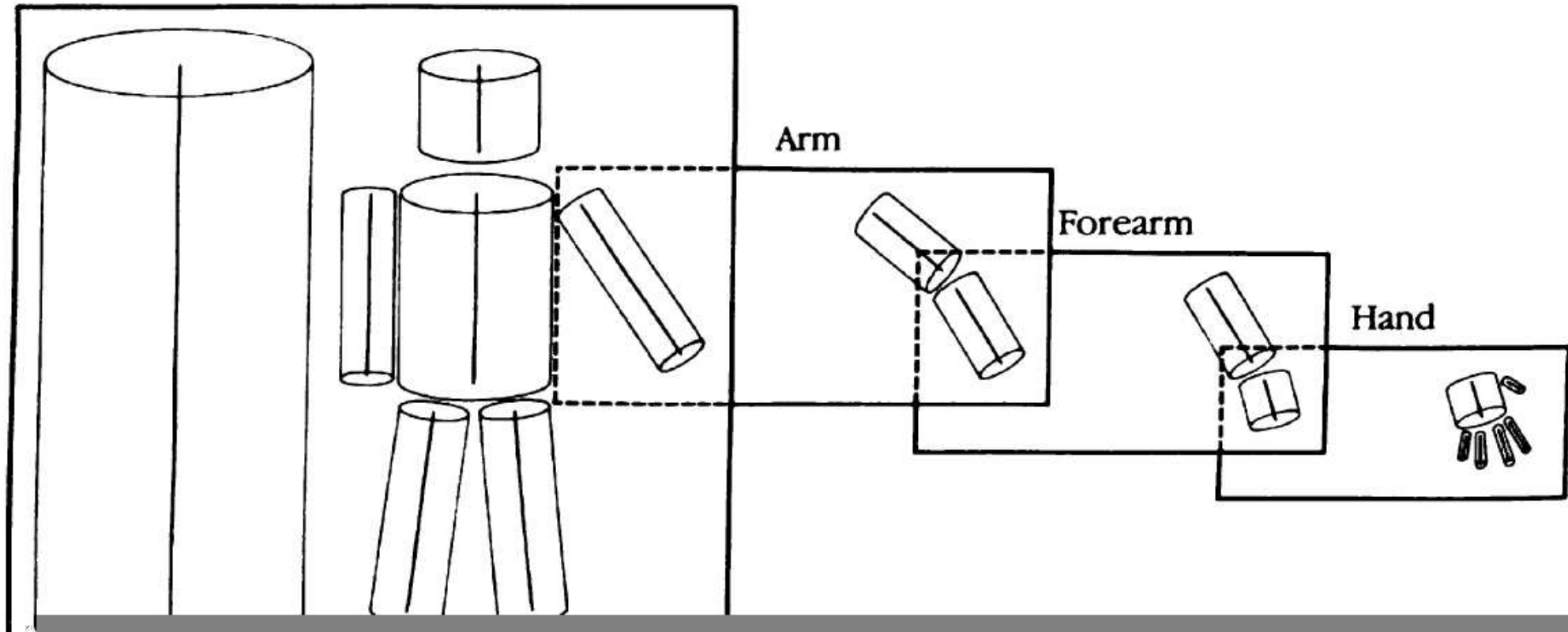
1. The perception of an event or object must include the simultaneous computation of several different representations of it, that capture diverse aspects of the use, purpose, or circumstance of the event or object.
2. That the various descriptions described in 1. include coarse versions as well as as fine ones. These coarse descriptions are a vital link in choosing the appropriate overall scenarios ...and in establishing correctly the roles played by the objects and actions that caused those scenarios to be chosen.

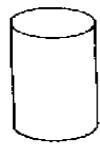
Human

Arm

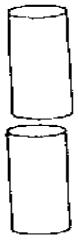
Forearm

Hand

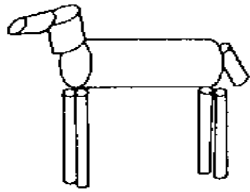




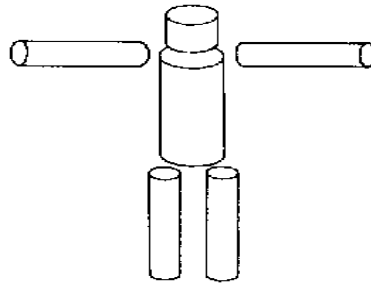
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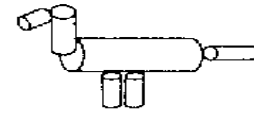
limb



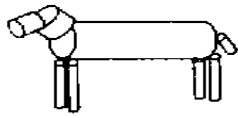
quadruped



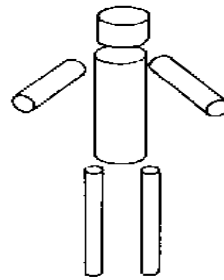
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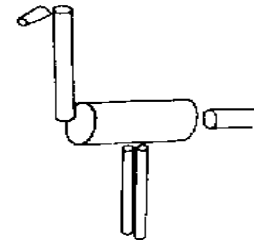
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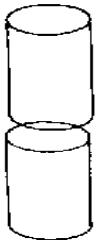
cow



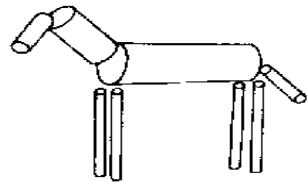
human



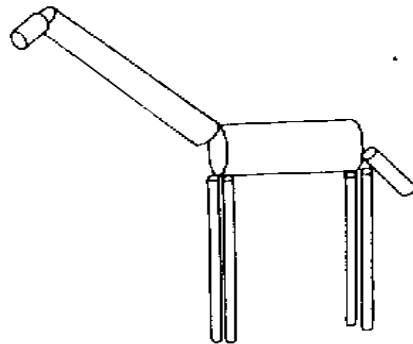
ostrich



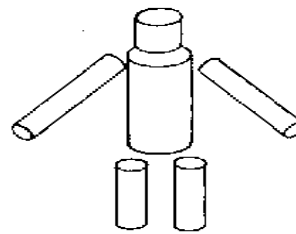
thick limb



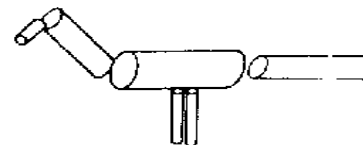
horse



giraffe



ape



dove



thin limb

## Eventualities as objects: event calculus

- (1) a. The flood occurred in the early morning hours.
  - b. The flood destroyed all our crops and we had to buy potatoes that year.
  - c. The whole property was crisscrossed with ditches, which prevented the flooding of the fields.
  - d. Flooding the fields at 14 cm depth for 2-3 months kills the worms.
- *flood* is an event type, as is *flooding of the fields*
  - *flooding* is a 'process', characterized e.g. by increase of submerged area and depth of water level—represented by fluent
  - both event types and can fill argument positions in verbs
  - event type is more like cylinder, fluent more like detailed shape – but no *ontological* difference

- (2) The flooding of the fields resulted in impacts to the salmon population, including outmigrating juvenile salmon being drawn into the unscreened water diversions.
- (3) This has the effect of flooding the fields surrounding Oxford rather than the city itself.
- (4) Flooding the fields can also cause higher egg mortality.
  - both event type and fluent can act as cause, but conceptualized differently
  - event type: like instantaneous change
  - fluent: like continuous change
  - but best to view the latter as a *refinement* of the first, in line with Marr's ideas

## Jean-Yves Girard, La logique comme géométrie du cognitif

Il y a d'autres intuitions de base qui ont été évacuées par la logique, ainsi la distinction essentielle entre *parfait* et *imparfait*, distinction rendu en français par le choix des temps, en russe par le changement de verbe. Cette nuance n'existe pas dans le monde vériste.

# A fundamental opposition in language: perfective and imperfective

- occurs in several areas of language: aspect, nominalization
- ‘*aspects* are different ways of viewing the internal temporal constituency of a situation’
- *nominalization*: the processes which turn verb phrases into nouns (or noun phrases)
- *perfective*: lack of explicit reference to the internal temporal constituency of a situation, viewing a situation from the outside
- *imperfective*: explicit reference to the internal temporal constituency of a situation, viewing a situation from the inside
- perfective like the top level in Marr’s hierarchy, imperfective like the lower levels (in the case of time, there is only one dimension as opposed to Marr’s three dimensions)

## Nominalization: examples from Google

- (5) a. The flood occurred in the early morning hours.  
b. The flood destroyed all our crops and we had to buy potatoes that year.  
c. The whole property was crisscrossed with ditches, which prevented the flooding of the fields.  
d. Flooding the fields at 14 cm depth for 2-3 months kills the worms.

- *flood*: derived nominal
- *flooding of the fields*: perfect nominal
- *flooding the fields*: imperfect nominal
- what is the *semantic* difference?
- do there exist other types? (perhaps in other languages?)

## Perfect nominals (correct examples from Google)

- (6)
- a. The singing of the song
  - b. The saving of us (Stevenson)
  - c. Deidre Haren begins the play with her beautiful singing of 'A Poultry Tale'
  - d. stunningly beautiful singing of Cenerentola.
  - e. the Passover slaying of Egypt's firstborn
  - f. It may be more difficult to imagine the aria's place in the drama or story of the whole opera when listening to *a recording of just that aria*.
  - g. On account of his deliberate buying up of stocks
  - h. \*the Passover slaying Egypt's firstborn
  - i. \*quickly cooking of the dinner.
  - j. \*having cooked of the dinner.
  - k. \*being able to cook of the dinner.
  - l. \*not revealing of the secret.

## Imperfect nominals (correct examples from Google)

- (7)
- a. \*The singing the song.
  - b. \*beautiful singing the song.
  - c. He also plays Johny Seoighe after *singing the song beautifully*.
  - d. quickly cooking the dinner.
  - e. On account of deliberately buying up stocks
  - f. *Having cooked the dinner* in our house for a number of years now...
  - g. Lisa gets Martin tucked into bed. Martin tells her he is sorry for *not being able to cook the dinner* he had planned for her.
  - h. *Never having cooked sausage meat* before this was quite a gamble.
  - i. The Catholic Church has been criticised for *not revealing the extent* of its possible involvement or complicity in the Holocaust ...

## Two kinds of objects: internal distinctions 1

- (8) not revealing the extent/ \*not revealing *of* the extent
- (9) singing the song beautifully/ \*singing *of* the song beautifully
- (10) not being able to cook the dinner/ \*not being able to cook *of* the dinner
- (11) never having cooked sausage meat/ \*never having cooked *of* sausage meat
- (12) the Passover slaying of Egypt's firstborn/ \*the Passover slaying Egypt's firstborn

This is not just a syntactic peculiarity, as witnessed by the *external distribution*

## Two kinds of objects: external distinctions

- (13) a. (Google) The video and the band's playing of the school's alma mater [*sic*] capped the evening.  
b. (Google) Clearly the Passover slaying of Egypt's firstborn occurred at midnight on the 15<sup>th</sup> of Nisan.  
c. (Google) The contract provides that *the* transfer of the assets and *undertaking of the business* is deemed to have occurred at midnight on 31 August.
- (14) \*Slaying Egypt's firstborn occurred at midnight on the 15<sup>th</sup> of Nisan.
- (15) a. They were surprised by a stranger coming in suddenly.  
b. (Google) The band's *playing of the song* is improving and there is some very interesting playing in thirds that we could never quite work out.
- (16) *The band's playing the song* is improving ... [OK]

These data suggest difference in *meaning*—not only in English!

## Difference in meaning between perfect and imperfect nominals

- same situation in the world described cognitively in different ways
  - (17) a. playing the song
    - b. playing of the song
- (17-b) is nontemporal: temporal parameter has to be added externally, e.g. using 'occur' (formally *Happens*)
- (17-a) in some sense still has temporal parameter, which allows one to 'go through' the eventuality

## Back to logic and the event calculus

- perfective  $\rightsquigarrow$  event type
- imperfective  $\rightsquigarrow$  fluent
- (but how?)
- this explains some distinctions in logical properties, once we know that *HoldsAt* is a *truth predicate*
- and this requires additional axioms

## On truth

- suppose given a formal language  $\mathcal{L}$ , with sentences  $\varphi$
- a model  $\mathcal{M}$  for  $\mathcal{L}$  determines which sentences are true (false).
- try to represent truth in  $\mathcal{M}$  by a *truth predicate*  $T$  (which takes sentences as arguments) such that

$$\mathcal{M} \models \varphi \iff T(\varphi)$$

- formally, we have extended  $\mathcal{L}$  to  $\mathcal{L}' = \mathcal{L} \cup \{T\}$ , with sentences  $\psi$
- can we have for  $\psi$  from  $\mathcal{L}'$

$$\mathcal{M} \models \psi \iff \mathcal{M} \models T(\psi)?$$

- suppose there is  $\psi$  satisfying  $\psi \leftrightarrow \neg T(\psi)$ , then (Tarski 1936)

$$\mathcal{M} \models \psi \iff \mathcal{M} \models \neg T(\psi) \iff \mathcal{M} \not\models \psi!!$$

- i.e. in classical logic,  $T$  can be defined only in the *metalanguage*

## One solution: Kleene's three-valued logic

- truth values *undecided* =  $u$ , *false* = 0 and *true* = 1, ordered via  $u \leq 0, u \leq 1$ .
- truth tables for  $\neg, \wedge, \vee$  ( $\rightarrow$  defined in terms of  $\neg, \vee$ )

		$p$	$q$	$p \wedge q$	$p$	$q$	$p \vee q$
		1	1	1	1	1	1
		0	0	0	0	0	0
$p$	$\neg p$	$u$	$u$	$u$	$u$	$u$	$u$
1	0	1	0	0	1	0	1
0	1	1	$u$	$u$	1	$u$	1
$u$	$u$	0	1	0	0	1	1
		0	$u$	0	0	$u$	$u$
		$u$	1	$u$	$u$	1	1
		$u$	0	0	$u$	0	$u$

## Truth in three-valued logic

- let  $\leftrightarrow$  mean:  $\varphi \leftrightarrow \theta$  is true if  $\varphi, \theta$  have the same truth value, and false otherwise;  $\leftrightarrow$  is two-valued.
- $\psi \leftrightarrow \neg T(\psi)$  is no longer contradictory: ensure that such  $\psi$  always have truth value  $u$ .

**Theorem 1** *"Any theory" can be consistently extended with a truth predicate in Kleene's three-valued logic.*

## HoldsAt as a truth predicate.

- truth predicate  $T(\bullet, \bullet)$  in extended sense

$$\mathcal{M} \models \varphi(a) \iff \mathcal{M} \models T(\varphi(x), a)$$

- *HoldsAt* is like  $T(\bullet, \bullet)$ , but the second argument always stands for time
- we *need* it because in the event calculus formulas may also occur as objects, in particular fluents
- ever since Gödel 1931: coding formulas as terms
- in our case we made a formula  $\varphi(t)$  act as a term (function or set)  $\{t \mid \varphi(t)\}$ , which is a fluent
- *Nominalization is strictly analogous to Gödel numbering.*

**Additional axioms for HoldsAt of the following type**

**Axiom' 4**  $HoldsAt(f_1, t) \wedge HoldsAt(f_2, t) \rightarrow HoldsAt(f_1 \wedge f_2, t)$

**Axiom' 5**  $\neg HoldsAt(f, t) \rightarrow HoldsAt(\neg f, t)$

Etc.