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Classifying Processes and Basic Formal Ontology

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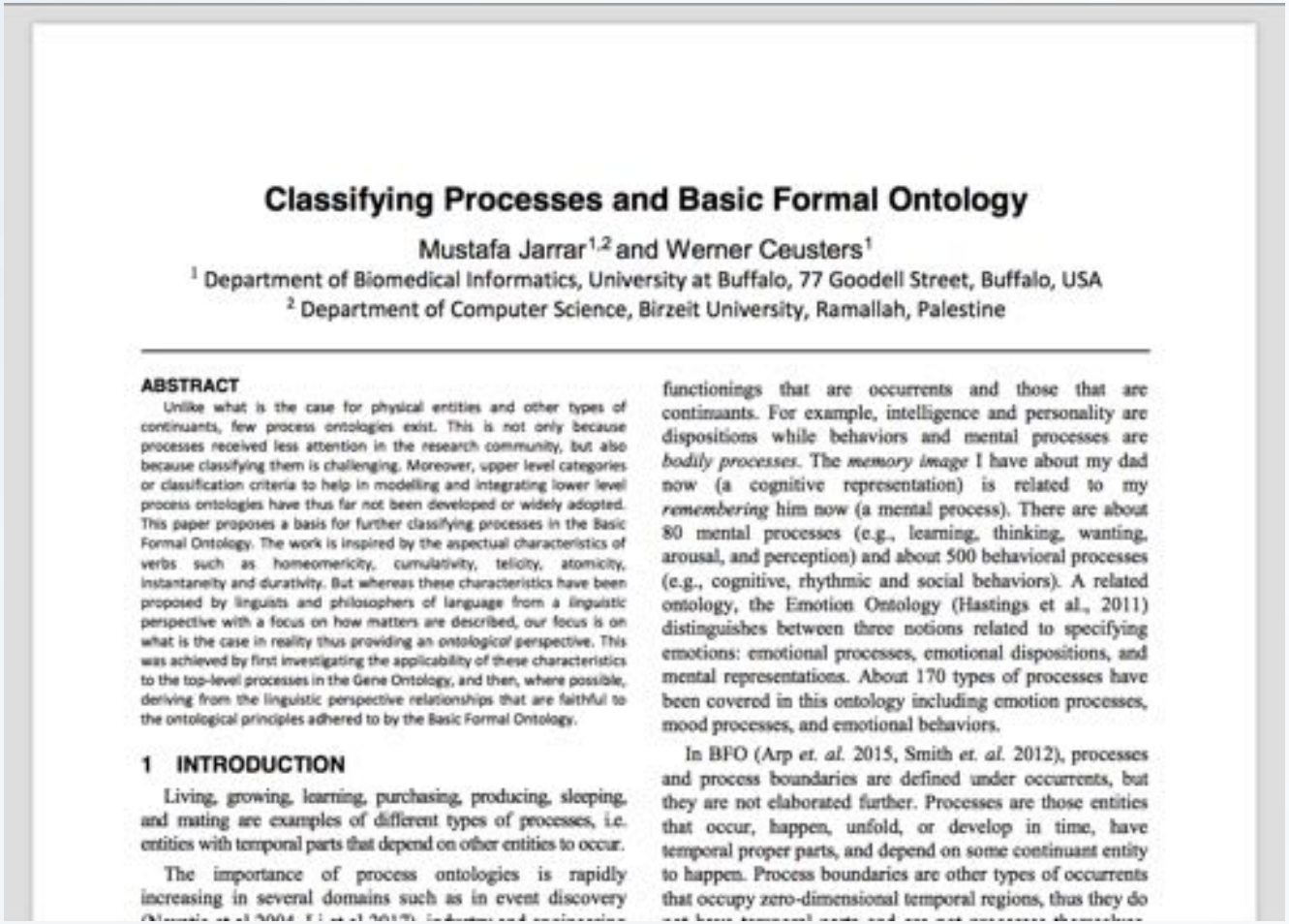

Classifying Processes and Basic Formal Ontology

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ABSTRACT

Unlike what is the case for physical entities and other types of continuants, few process ontologies exist. This is not only because processes received less attention in the research community, but also because classifying them is challenging. Moreover, upper level categories or classification criteria to help in modelling and integrating lower level process ontologies have thus far not been developed or widely adopted. This paper proposes a basis for further classifying processes in the Basic Formal Ontology. The work is inspired by the aspectual characteristics of verbs such as homeomericity, cumulativity, telicity, atomicity, instantaneity and durativity. But whereas these characteristics have been proposed by linguists and philosophers of language from a *linguistic* perspective with a focus on how matters are described, our focus is on what is the case in reality thus providing an *ontological* perspective. This was achieved by first investigating the applicability of these characteristics to the top-level processes in the Gene Ontology, and then, where possible, deriving from the linguistic perspective relationships that are faithful to the ontological principles adhered to by the Basic Formal Ontology.

1 INTRODUCTION

Living, growing, learning, purchasing, producing, sleeping, and mating are examples of different types of processes, i.e. entities with temporal parts that depend on other entities to occur.

The importance of process ontologies is rapidly increasing in several domains such as in event discovery

functionings that are occurrents and those that are continuants. For example, intelligence and personality are dispositions while behaviors and mental processes are *bodily processes*. The *memory image* I have about my dad now (a cognitive representation) is related to my *remembering* him now (a mental process). There are about 80 mental processes (e.g., learning, thinking, wanting, arousal, and perception) and about 500 behavioral processes (e.g., cognitive, rhythmic and social behaviors). A related ontology, the Emotion Ontology (Hastings et al., 2011) distinguishes between three notions related to specifying emotions: emotional processes, emotional dispositions, and mental representations. About 170 types of processes have been covered in this ontology including emotion processes, mood processes, and emotional behaviors.

In BFO (Arp *et. al.* 2015, Smith *et. al.* 2012), processes and process boundaries are defined under occurrents, but they are not elaborated further. Processes are those entities that occur, happen, unfold, or develop in time, have temporal proper parts, and depend on some continuant entity to happen. Process boundaries are other types of occurrents that occupy zero-dimensional temporal regions, thus they do

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http://www.jarrar.info/publications/JC17.pdf

Motivation

Examples of processes: Living, growing, learning, purchasing, producing, sleeping, mating, feeding, eating, cooking, tasting,….

➔ Those entities with temporal parts that depend on other entities to occur.

- Few process ontologies exist,
  E.g., Gene Ontology, Emotion Ontology, Mental Functioning Ontology,..
- Classifying processes is challenging!
- Process ontologies are rapidly increasing in e.g., Bioinformatics, event discovery, industry and engineering, software engineering, affective computing, among others.

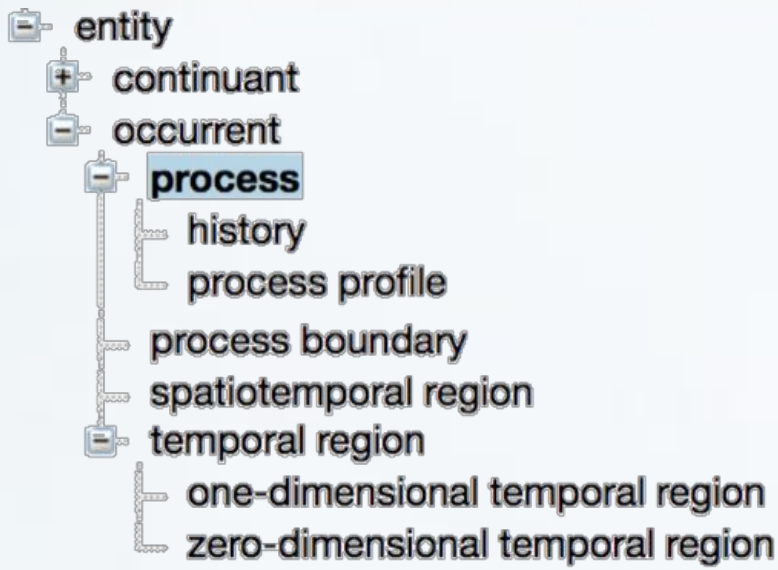
Goals

We proposes a basis for classifying processes in **BFO**

- Inspired by verb semantics and the aspectual characteristics of verbs.
- We attempted to revise and redefine (homeomericity, cumulativity, telicity, atomicity, instantaneity and durativity).

- In mainstream approaches, these characteristics are focused on how matters are described, but here our focus is on what is the case in reality thus providing an ***ontological perspective***, mainly BFO.

Processes in BFO



Processes occur, happen, unfold, or develop in time, have temporal proper parts, and depend on some continuant entity to happen.

Process boundaries (e.g., midnight, departure, arrival) occupy zero-dimensional temporal regions, thus they do not have temporal parts.

Process boundaries are not processes themselves.

Processes in DOLCE

- Perdurants happen in time, by accumulating different temporal parts: thus at any time *t* at which they exist, only their temporal parts at *t* are present.
    - Statives are cumulative, while evens are not.
    - Achievements are atomic, while accomplishments are not.
    - States are homeomeric, while processes are not.
- DOLCE used homeomericity and cumulativity (from lexical semantics), but these notions remain unclear.

DOLCE – BFO:

Accomplishment → bfo:process.

Achievements → bfo:ProcessBoundary(!)

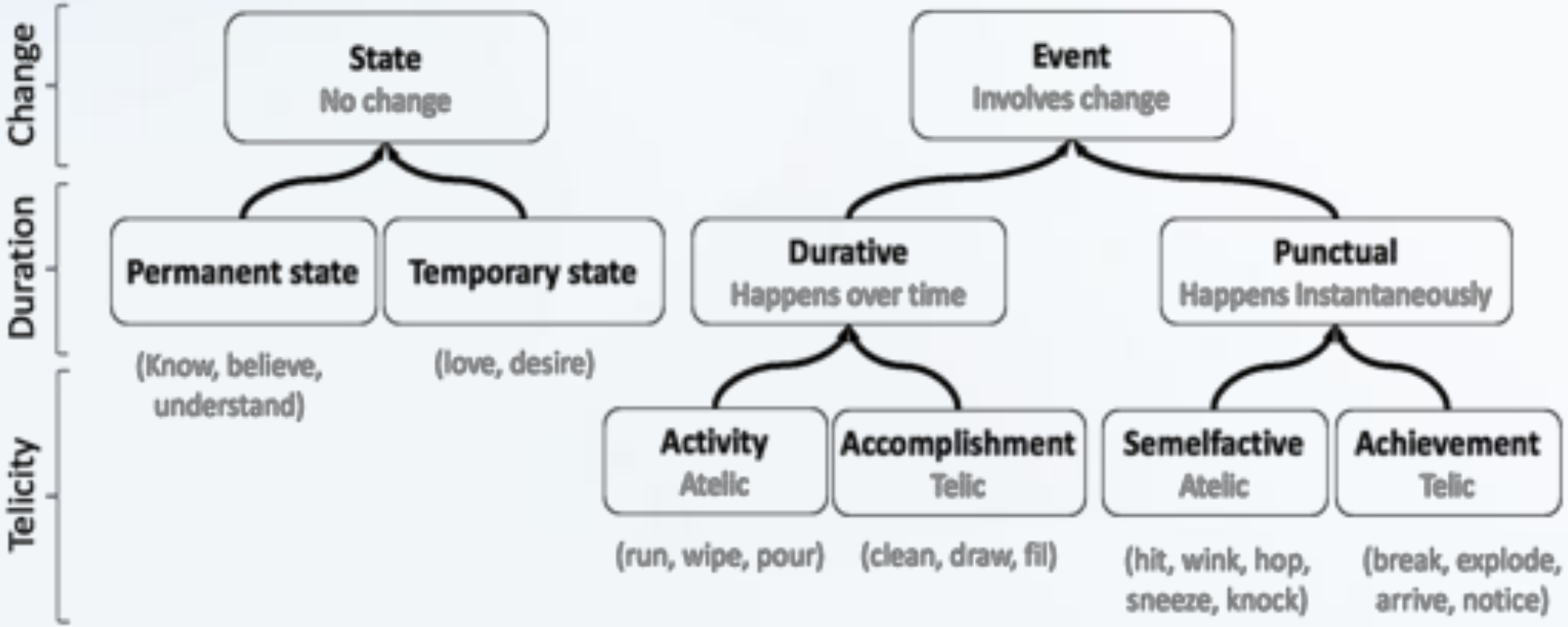
Process → bfo:process.

States → bfo: ? (not bfo:process)

"Events" in Philosophy and Linguistics

- **Semantics of verbal phrases**, called 'lexical aspect' of verbs:
  (Casati et al 2015, Mourelatos 1978, Bach 1986, Krifka 1998, Caudal et al. 2005, Trypuz et al 2007):
  - **Different Notions** like actions, activities, accomplishments, achievements, processes, performances states, mental and physical events, bodily movements, …
  - **Different Criteria** like homeomericity, cumulativity, atomicity, telicity, durativity and instantaneity. Other aspectual notions, such as incrementality and structure, distributivity and collectivity, and quantization, …

- Our summary of the literature (e.g., Moens et al 1988, Bhatt 2005, Levin 2009, …):



"Events" in Philosophy and Linguistics

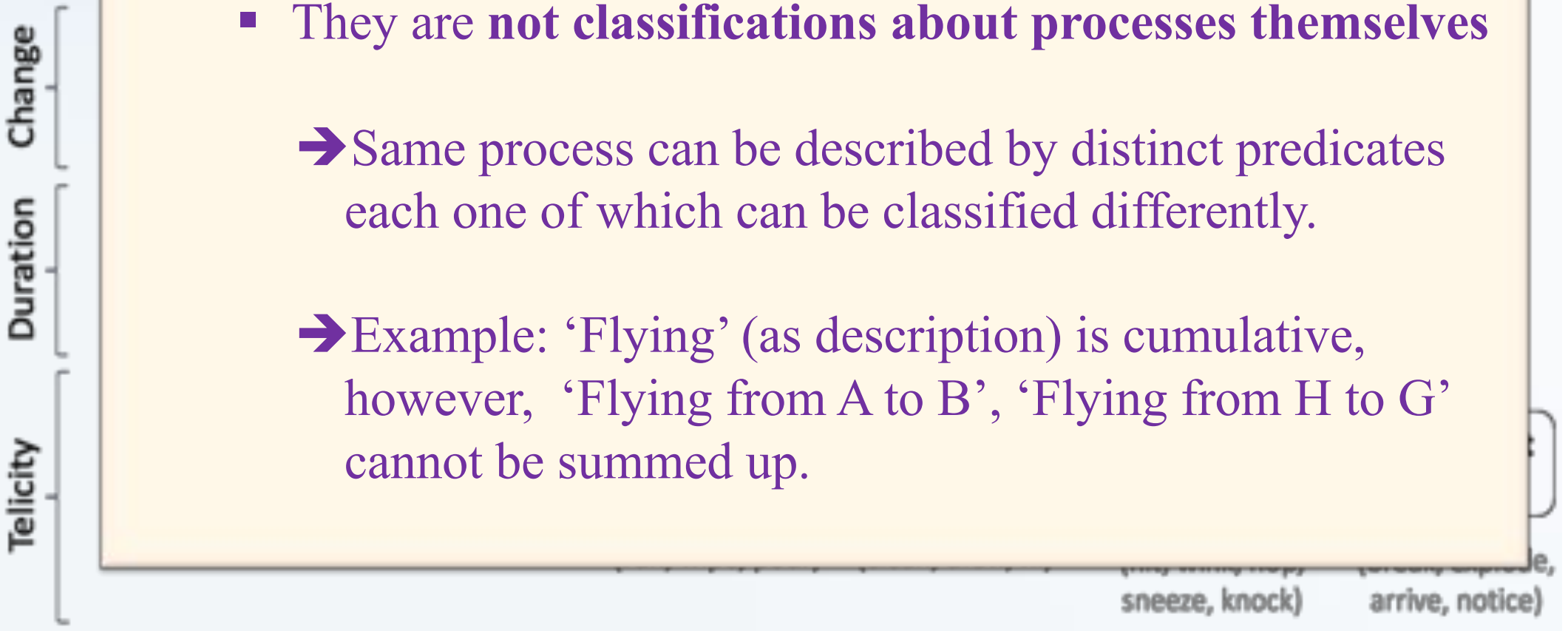
- **Semantics of verbal phrases**, called 'lexical aspect' of verbs:

Krifka made it clear (Krifka 1998):

- '***these classifications are about predicates***', i.e. descriptions, denoting entities such as processes in reality,
- They are **not classifications about processes themselves**

➔Same process can be described by distinct predicates each one of which can be classified differently.

➔Example: 'Flying' (as description) is cumulative, however, 'Flying from A to B', 'Flying from H to G' cannot be summed up.



Our Proposal

Revise and redefine:

1. **Homeomericity**
2. **Cumulativity**
3. **Telicity**
4. **Instantaneity and durativity**
5. **Atomicity**

Definitions (Temporal parts Vs Occurrent parts)

- *Your-life* **is an instance of** a process.
- The *first-year-of-your-life* **is a temporal part of** *your-life*
- *Your-Trip-to-Newcastle* **is an occurrent part of** *your-life*

p **occurrent-part-of** *q*

a primitive relation of parthood holding independently of time between two process instances when one is a sub-process of the other (Arp et al 2015:135).

P ***occurrent-part-of*** Q =def.:

for every particular occurrent *p*, if *p* **instance-of** P, then there is some particular occurrent *q* such that *q* **instance-of** Q and *p* **occurrent-part-of** *q* (Arp et al 2015:139).

p **temporal-part-of** *q* =def.:

p **occurrent-part-of** *q*
& for some temporal region r *p* **spans** *r*
& for all occurrents *c*, *r′*
if (*c* **spans** *r′* & *r′* **occurrent-part-of** *r*
then (*c* **occurrent-part-of** *p* iff *c* **occurrent-part-of** *q*)) (Smith 2012, corrected).

P ***temporal-part-of*** Q =def.:

for every particular occurrent *p*, if *p* **instance-of** P, then there is some particular occurrent *q* such that *q* **instance-of** Q and *p* **temporal-part-of** *q*.

1- Homeomericity

An occurrence (in DOLCE) is homeomeric iff all of its temporal parts (in BFO sense) are of the same process type.

- Example: 'sitting' is homeomeric, as we cannot find any temporal part of setting that is not setting.
- Similar to *homogeneity* (Dowty 1977:60).
- This is a property of universals, not of instances.
- BFO's classification is based on instances, not of universals.

1- Homeomericity (Proposed Definitions)

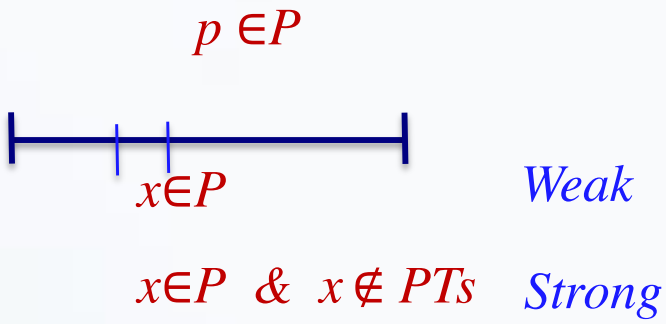
p **isotypic-part-of** *q* =def.

p **temporal-part-of** *q*

& *p* **instance-of** all types instantiated by *q*.

p **weakly-homeomeric-in** P =def.

all temporal parts of *p* which are not process boundaries are instances of P



p **strongly-homeomeric-in** P =def.

all temporal parts of *p* which are not process boundaries are instances of P and there is no such part of *p* that instantiates a subtype of P.

Examples:

- **The-growth-in-your-body is weakly-homeomeric-in Growth**, as every temporal part of the-growth-in-your-body is an instance of Growth.
- **The-growth-in-your-body is strongly-homeomeric-in Growth**, as every temporal part of the-growth-in-your-body is an instance of Growth; and no temporal part of the-growth-in-your-body can be an instance of any of the Growth subtypes.

2- Cumulativity

An occurrence is cumulative if the mereological sum of two instances of the same type is also an instance of the same type.

- Example: '*the sum of two sittings is still a sitting*'.
- Extensively discussed in the literature (e.g., Krifka 1989, Champollion 2014)
- To describe verbs – not processes!
  - also used for mass vs. count nouns: two portions of water make one (bigger) portion of water, two bottles of water together do not make one (bigger) bottle.

- Adopted by DOLCE, but remains unclear
  - What mereological sum is intended (occurrent vs. temporal parts)
    - My sitting + your sitting = sitting?
    - My sitting [13:00 -14:00] + My sitting [14:00 -15:00] = Sitting [13:00-15:00] ?
    - Flying is cumulative? Flying to London is cumulative?
  - Is it a property of processes? or of how a process is described?

➔ Champollion 2014 & Galton 2016: cumulativity is related to process description, rather than what it is ontologically.

2- Cumulativity (Proposed Definitions)

p **cumulative-with** *q* =def.
all process types instantiated by *p* and all process types instantiated by *q* are instantiated by *p*, *q* and *p*+*q*.

P ***cumulative-in*** Q =def.
P *isa* Q
& for all p_1, p_2 **instance-of** P: (p_1+p_2) instance-of Q.

➔ If a process *p* is at least **weakly-homeomeric-in** P then it is also **instance-of** a type which is *cumulative-in* P, but not vice versa.

Examples:

- Subtypes of Growth (e.g., Cell growth, Heart growth, ...) are ***cumulative-in*** Growth, also they are ***weakly-homeomeric-in*** Growth.
- Subtypes of Cell Aggregation (e.g., Cartilage Condensation) are ***cumulative-in*** Cell Aggregation (the mereological sum of two Cartilage Condensations would be a cell aggregation), however, they are not **strongly-homeomeric-in** Cell Aggregation (as parts of them, e.g., “cells coming close to each other” are not aggregation…).

3- Telicity

Telic: action tending towards a goal or a terminal point (Garey 1957)

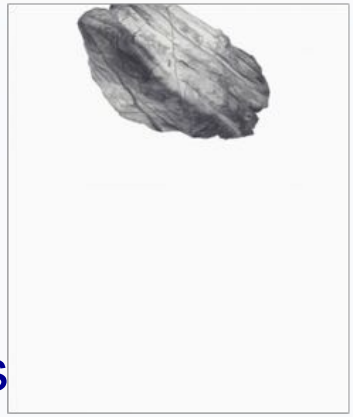
- "running" is atelic
- "running a marathon" is telic,
- "writing" is atelic
- "writing an article" is telic

Can we apply telicity to *processes themselves?*, rather than to predicates under which these processes are *described*?

- In BFO terms, is telicity a notion that applies only to representational units, or can it also be applied to that what the representational units are about?

3- Telicity (Proposed Definitions)

Are there processes that are terminated naturally?

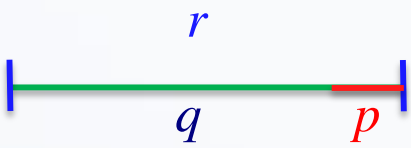


- "Falling"!
- Can a rock keeps falling down forever?
- It stops when reaching a surface.

➔'*falling* under natural earth conditions' is a telic process

- It is followed by a "coming to stop, when reaching a surface" process that terminates it.

"Falling" ***is-telic-in*** *"Moving". "Coming to stop" terminates "Falling"*
Moving = "Falling" + "Coming to stop".



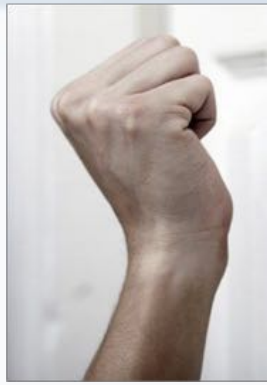
***p* is-telic-in** R =def.

***p* instance-of** P

& there exists some process *q* **instance-of** Q and some process *r* **instance-of** R, such that

(1) *q* not **instance-of** P,
(2) *p* not **instance-of** Q,
(3) *p* **precedes** *q*, and
(4) *p* and *q* are **temporal-part-of** *r*.

4- Instantaneity

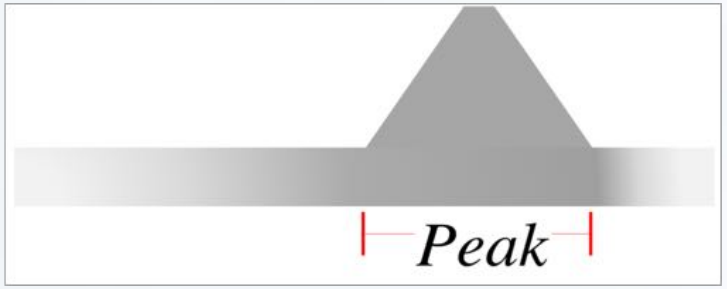


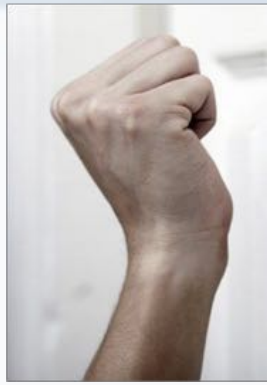
- Instantaneous Vs. durative!
- *Instantaneous* (also called *punctual*) takes just a moment, a complete action with no explicit internal temporal structure (Garey 1957, Mourelatos 1978, Krifka 1998).
- Examples: knocking, hitting, blinking, arriving, departing.

➢ There are no processes that develop in zero-time.

➢ The arrival **process boundary** vs. the arriving **process**.

4- Instantaneity (Proposal)





- We propose processes with **peak moment**, “touching-the-door” in “knocking”

- All parts of knocking before and after the peak moment alone are not knocking.

- Instantaneous processes cannot be **strongly-homeomeric-in** some universal because their temporal parts before and after their peak are not of the same type.

- Boundaries of instantaneous processes are typically *fiat boundaries*

5- Atomicity

- A one-step change-of-state, lacking any internal sub events (Caudal et al. 2005, Krifka 1998).

- Adopted by DOLCE to distinguish between accomplishments (non-atomic) and achievements (atomic).

- Atomicity depends on the granularity level and is subject to one's perspective!

- We are not sure yet whether this is a fantasy or something essential.

Annotating the Gene Ontology Processes

To test the applicability of these notions, we used them to analyze and annotate the 35 most top level processes in the Gene Ontology.

Home.	Cumu.	Telic	Inst.	Process
Y	Y	N	N	Growth
N	N	Y	N	Reproduction
N	N	N	Y	Biological Adhesion
N	Y	N	N	Cell Aggregation
N	Y	N	N	Pigmentation
Y	Y	N	N	Locomotion
N	Y	Y	N	Acquisition of nutrients from otl
Y	Y	N	N	Feeding on or from other organi
N	Y	Y	N	Carbohydrate utilization

The full annotations can be accessed online

http://github.com/mjarrar2/Processontology/wiki

We plan to fully annotate the top levels of the Gene Ontology processes.

Conclusion and Future Work

- We examined the re-use of aspectual notions used to classify verbal phrases for building process ontologies under BFO.

- We provided BFO-compatible interpretations of homeomericity, cumulativity and telicity, discussed instantaneity, and rejected atomicity.

- We plan to explore the use these notions to build a process profile ontology in BFO.

References

- Arp R, Smith B, Spear AD. 2015. Building ontologies with Basic Formal Ontology. MIT Press.
- Bach, E. 1986. The algebra of events. Linguistics & philosophy, 9(1),5-16.
- Bhatt, R., & Pancheva, R. 2005. The syntax and semantics of aspect. LSA Summer Institute handout, Cambridge, MA.
- Casati, R., Varzi, A. 2015. Events, The Stanford Encyclopedia of Philosophy (Winter 2015 Edition), Edward N. Zalta (ed.)
- Caudal, P., & Nicolas, D. 2005. Types of degrees and types of event structures. Event arguments: Foundations and applications, 277-300.
- Champollion, L. 2014. Distributivity, collectivity and cumulativity. Wiley's companion to semantics.
- Dowty, D. 1977 Toward a Semantic Analysis of Verb Aspect and the English 'Imperfective' Progressive. Linguistics & Philosophy, 1(1):45-77
- Galton, A. 2016. The Ontology of Time and Process. Third Interdisciplinary School on Applied Ontology, Bozen-Bolzano, Italy
- Garey, H. B. 1957. Verbal Aspects in French. Language 33, 91-110.
- Gene Ontology Consortium. 2001. Creating the gene ontology resource: Design and implementation. Genome Res, 11:1425–1433.
- Hastings, J., Ceusters, W., Smith, B., Mulligan, K. 2011. Dispositions and processes in the Emotion Ontology. Proceedings of ICBO 2011.
- Hastings, J., Smith, B., Ceusters, W., Jensen, M., Mulligan, K. 2012. Representing mental functioning: Ontologies for mental health and disease. Proceedings of ICBO 2012.
- Hennig, B. 2008. Occurrents. In Munn, K., Smith, B. (Eds.) Applied Ontology: An Introduction, chapter 12 (pp 255-284)
- Krifka, Manfred. 1998 The origins of telicity". In Susan Rothstein (ed.), Events and Grammar. Dordrecht: Kluwer, 197-235.
- Krifka, Manfred. 1989. "Nominal reference, temporal constitution and quantification in event semantics". In Semantics and Contextual Expressions 75-115. Dordrecht: Foris.
- Levin, B. 2009. Aspectual Approaches to Lexical Semantic Representation. Course LSA 116 UC Berkeley
- Li, M., Wang, D., Lu, Q., Long, Y . 2016. Event Based Emotion Classification for News Articles. PACLIC 30, 153.
- Li, C., Bendersky, M., Garg, V., Ravi, S. 2017. Related Event Discovery. Proceedings of WSDM '17. ACM, New York, USA, 355-364.
- Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A., Oltramari, R., Horrocks, I. 2002. The WonderWeb library of foundational ontologies and the DOLCE ontology. WonderWeb deliverable D18.
- Moens, M., & Steedman, M. 1988. Temporal ontology and temporal reference. Computational linguistics, 14(2), 15-28.
- Morbach, J., Yang, A., Marquardt, W. 2007. OntoCAPE -A large-scale ontology for chemical process engineering. Engineering applications of artificial intelligence, 20(2), 147-161.
- Mourelatos, A. P. 1978. Events, processes, and states. Linguistics and philosophy, 2(3), 415-434.
- Nevatia, R., Hobbs, J., Bolles, B. 2004. An ontology for video event representation. Proceedings of CVPRW'04. IEEE
- Ruy, F. B., Falbo, R. A., Barcellos, M. P., Guizzardi, G., Quirino, G. K. 2015. An ISO-based software process ontology pattern language and its application for harmonizing standards. ACM SIGAPP.15(2), 27-40.
- Smith B. 2012. Classifying processes: an essay in applied ontology. Ratio. December 1; 25(4): 463–488
- Smith, B., et al .2012. Basic Formal Ontology 2. Specification and User's Guide, (version 3/6/2014).
- Smith, B., & Varzi, A. C. 2000. Fiat and bona fide boundaries. Philosophical and Phenomenological Research, 401-420.
- Trypuz, R., Vieu, L. 2007. An ontology of the aspectual classes of actions. Proceedings of LogKCA-07. 393-409.
- Vendler, Z. 1957. Verbs and times. The philosophical review, 143-160.