From Montague Semantics to MTT-Semantics: A Meaningful Comparison

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Dependent Types in Event Semantics

- What is a dependent type?
  - An example of its use in linguistic semantics, involving:
    1. Refined (dependent) types of events Evt(h)
    2. Parameterised coercion (coercion whose type is Π-type)
- Dependent event types (Luo & Soloviev, WoLLIC 2017)
  - DETs in the Montagovian/Davidsonian setting
    - Do this for the sake of easier understanding (and further applications).
    - You can add DETs to MTTs (MTT-event semantics) – omitted here.
  - Event quantification problem and its solution with DETs
  - Formal extension of simple type theory by DETs (and its meta-theoretic properties)

What is a dependent type?

- Dependent type
  - A type that depends on objects.
    - Vect(n) – type of lists $[a_1, \ldots, a_n]$ whose length is n
    - Child(h) – type of children of h (h : Human)
    - Evt(h) – type of event whose agent is h
  - Note: a dependent type is *not* a type depending on types.
    - Pred(A) = A→Prop depends on type A, but it is not a dependent type.

An example

- Example:

    Julie just started *War and Peace*, which Tolstoy finished after many years of hard work. But that won't last because she never gets through long novels.

- Formal semantics?
  - This example in (Asher & Luo 2012) was the first use of parameterised coercions for linguistic semantics in literature.
- Three issues
  - Linguistic coercions
  - Multiple coercions (for "start/finish/last W&P"): which one?
    - start W&P → start writing/reading W&P

Linguistic coercions

- Representing linguistic coercions
  - By coercions in the framework of coercive subtyping
- Consider

Julie enjoyed a book.

$$\exists x : Book.\ enjoy(j, x)$$

- Is the formula well-typed? Well, only yes if:

$$Book \leq_{reading} Event,$$

Julie enjoyed reading a book.

$$\exists x : Book.\ enjoy(j, reading(x))$$

- Coercion "reading" is of type Book→Event.

Multiple coercions

- The following two need different coercions:
  - Julie started W&P. (start W&P → start reading W&P)
  - Tolstoy finished W&P. (finish W&P → finish writing W&P)
- Coercion scopes interleave & overlap, for example, in the above paragraph,
  - Coercions "reading" (for start/last) and "writing" (for finish) have interleaving and overlapping scopes.
- How to deal with this?
  - Use parameterised coercions, those with parameters quantified by Π.

- Assume:

$$start,\ finish,\ last : \Pi h : Human.\ (Evt(h) \rightarrow Prop)$$

$$read,\ write : \Pi h : Human.\ (Book \rightarrow Evt(h))$$

- Consider coercions
  - $c : \Pi h{:}Human.\ Book \rightarrow Evt_A(h)$

$$Book \leq_{c(h)} Evt_A(h) \text{ for } h : Human.$$

$$c(h,b) = \begin{cases} write(h,b) & \text{if } h \text{ wrote } b, \\ read(h,b) & \text{otherwise.} \end{cases}$$

) Julie just started *War and Peace*, which Tolstoy finished after many years of hard work. But that won't last because she never gets through long novels.

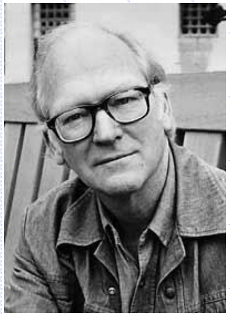
$$
\begin{aligned}
& start(j, W\&P) \\
\& \ & finish(t, W\&P) \\
\& \ & \neg last(j, W\&P) \\
\& \ & \forall lb : (\Sigma b{:}Book.long(b)).\ finish(j, \pi_1(lb))
\end{aligned}
$$

$$
\begin{aligned}
& start(j, c(j, W\&P)) \\
\& \ & finish(t, c(t, W\&P)) \\
\& \ & \neg last(j, c(j, W\&P)) \\
\& \ & \forall lb : (\Sigma b{:}Book.long(b)).\ finish(j, c(j, \pi_1(lb)))
\end{aligned}
$$

$$
\begin{aligned}
& start(j, read(j, W\&P)) \\
\& \ & finish(t, write(t, W\&P)) \\
\& \ & \neg last(j, read(j, W\&P)) \\
\& \ & \forall lb : (\Sigma b{:}Book.long(b)).\ finish(j, c(j, \pi_1(lb)))
\end{aligned}
$$

- A detailed analysis of one of the formulas:
  - start(j, W&P) start(j) : Evt(j)→Prop
    = start(j, c(j,W&P)) W&P : Book $<_{c(j)}$ Evt(j)
    = start(j, reading(W&P)) by defn of c(j)
  - Similarly, eg, finish(t, W&P) = finish(t,writing(&P)).
- Therefore, the semantics is correct as intended.

Davidsonian event semantics



- Original motivation: adverbial modifications

  (1) John buttered the toast.

  (2) John buttered the toast with the knife in the kitchen.

  Do we have (2) $\Rightarrow$ (1)?

  - Cumbersome in MG with meaning postulates (next slide)
  - Davidson (1967): verbs tacitly introduce existentially quantified events, doing away with meaning postulates.

- In neo-Davidsonian notation (1980s) with thematic roles (slide)

  (1′) ∃e:Event. butter(e)
  & agent(e)=john & patient(e)=toast

  (2′) ∃e:Event. butter(e) & with(e,knife) & at(e,kitchen)
  & agent(e)=john & patient(e)=toast

  Obviously, (2′) $\Rightarrow$ (1′)

MG approaches without events

- (1) John buttered the toast.
  (1s) butter(john,toast), where butter : $\mathbf{e}^2 \rightarrow \mathbf{t}$.
- (2) John buttered the toast with the knife in the kitchen.
  (2s) butter(j,t,k,m), where butter : $\mathbf{e}^4 \rightarrow \mathbf{t}$
  (2t) kitchen(knife(butter(john)))(toast),
  where butter : $\mathbf{e}^2 \rightarrow \mathbf{t}$, knife/kitchen : $(\mathbf{e} \rightarrow \mathbf{t}) \rightarrow (\mathbf{e} \rightarrow \mathbf{t})$
- Both need meaning postulates to get, eg,
  (2s) $\Rightarrow$ (1s)
  (2t) $\Rightarrow$ (1s)
  rather ad hoc.

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Major thematic relations [edit]

Here is a list of the major thematic relations.[3]

- **Agent**: deliberately performs the action (e.g., **Bill** ate his soup quietly.).
- **Experiencer**: the entity that receives sensory or emotional input (e.g. **Susan** heard the song. **I** cried.).
- **Stimulus**: Entity that prompts sensory or emotional feeling - not deliberately (e.g. David Peterson detests **onions!**).
- **Theme**: undergoes the action but does not change its state (e.g., We believe in one **God**. I have **two children**. I put **the book** on the table. He gave **the gun** to the police officer.) (Sometimes used interchangeably with patient.)
- **Patient**: undergoes the action and changes its state (e.g., The falling rocks crushed **the car**.). (Sometimes used interchangeably with theme.)
- **Instrument**: used to carry out the action (e.g., Jamie cut the ribbon **with a pair of scissors**.).
- **Force** or **Natural Cause**: mindlessly performs the action (e.g., **An avalanche** destroyed the ancient temple.).
- **Location**: where the action occurs (e.g., Johnny and Linda played carelessly **in the park**. I'll be **at Julie's house** studying for my test.).
- **Direction** or **Goal**: where the action is directed towards (e.g., The caravan continued on **toward the distant oasis**. He walked **to school**.).
- **Recipient**: a special kind of goal associated with verbs expressing a change in ownership, possession. (E.g., I sent **John** the letter. He gave the book **to her**.)
- **Source** or **Origin**: where the action originated (e.g., The rocket was launched **from Central Command**. She walked **away from him**.).
- **Time**: the time at which the action occurs (e.g., The pitcher struck out nine batters **today**)
- **Beneficiary**: the entity for whose benefit the action occurs (e.g.. I baked **Reggie** a cake. He built a car **for me**. I fight **for the king**.).
- **Manner**: the way in which an action is carried out (e.g., **With great urgency**, Tabitha phoned 911.).
- **Purpose**: the reason for which an action is performed (e.g., Tabitha phoned 911 right away **in order to get some help**.).
- **Cause**: what caused the action to occur in the first place; not *for what*, rather *because of what* (e.g., **Because Clyde was hungry**, he ate the cake.).

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Problems in Event-semantics + Montague

- For example, "event quantification problem" (EQP)
- Incompatibility between event semantics and MG.

(1) Nobody talked.

Intended neo-Davidsonian event semantics is (2):

(2) $\neg\exists x{:}\mathbf{e}.\ \mathrm{human}(x)\ \&\ \exists v{:}\mathrm{Event}.\ \mathrm{talk}(v)\ \&\ \mathrm{agent}(v,x)$

But the incorrect semantics (3) is also possible – it is well-typed:

(3) $\exists v{:}\mathrm{Event}.\ \neg\exists x{:}\mathbf{e}.\ \mathrm{human}(x)\ \&\ \mathrm{talk}(v)\ \&\ \mathrm{agent}(v,x)$

which moves the event quantifier "$\exists v{:}\mathrm{Event}$" in (2) to the left.

Some proposed solutions to EQP

- Many different proposals (only mentioning two below)
  - Purpose: to force scope of event quantifier to be narrower.
- Champollion's quantificational event sem. [2010, 2015]
  - Trick: taking a set E of events as argument, but **talk**(e) …
    - talk : (Event→**t**)→**t** with talk(E) = ∃e:Event. e∈E & **talk**(e)
  - Debatable: intuitive meanings, compositionality & complexity
- Winter-Zwarts [2011] & de Groote [2014]
  - Use Abstract Categorial Grammar (see, eg, [de Groote 01])
    - ACG structure prevents incorrect interpretation.
  - Seemingly coincidental (and what if one does not use ACG?)
- Our proposal: dependent event types (solution to EQP & …)

Dependent event types [Luo & Soloviev (WoLLIC17)]

- Dependent event types
  - Refining event structure by (dependent) typing
  - Applications include
    - A solution to EQP
    - Selection restrictions in MTT-semantics with events
- How:

  Refining event structure:

  Event ➔ Evt(a)/Evt(a,p)

  which are event types dependent on thematic roles a/p, called agents/patients, respectively.

DETs and their subtyping relationships

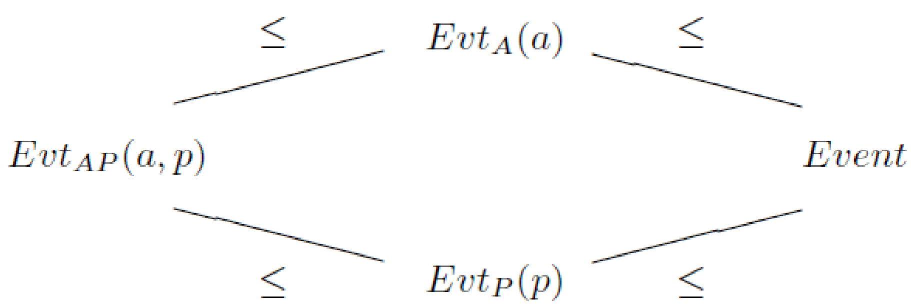
- For a:Agent and p:Patient, consider DETs

$$\text{Event},\ Evt_A(a),\ Evt_P(p),\ Evt_{AP}(a,p)$$

- Subsumptive subtyping

$$\frac{a : A \qquad A \leq B}{a : B}$$

- Subtyping between DETs (eg, Any event with agent a and patient p is an event with agent a.)



Two systems with DETs

- Extension of Montague's simple TT with DETs
  - C_e extends Church's STT (1940) with DETs
  - Montague's system is familiar for many – hopefully better understanding of DETs.
- Extension of modern type theories with DETs
  - T[E] extends type theory T with DETs (e.g., T = UTT).
  - This shows how DETs work in MTTs.

(Here, we only present C_e, for the sake of easier understanding and applications.)

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Dependent event types in Montagovian setting

- Eg. John talked loudly.
  - talk, loud : Event→**t**
  - agent : Event→**e**→**t**
- (neo-)Davidsonian event semantics

  $$\exists e : Event.\ talk(e)\ \&\ loud(e)\ \&\ agent(e, j)$$
- Dependent event types in Montagovian setting:

  $$\exists e : Evt_A(j).\ talk(e)\ \&\ loud(e)$$

  which is well-typed because $Evt_A(j) \leq Event$.

C_e: extending Church's simple TT with DETs

- First, Church's simple type theory (1940)
  - Employed in Montague's semantics (c.f., Gallin 1975)
  - Its rules are presented in the Natural Deduction style as follows.

- Rules for sorts/judgements and λ-calculus

$$\frac{}{\mathbf{e}\ type} \qquad \frac{}{\mathbf{t}\ type} \qquad \frac{}{x : A\ [x : A]} \qquad \frac{}{P\ true\ [P\ true]}$$

$$\frac{A\ type \quad B\ type}{A \to B\ type} \qquad \frac{b : B\ [x : A] \quad x \notin FV(B)}{\lambda x{:}A.b : A \to B} \qquad \frac{f : A \to B \quad a : A}{f(a) : B}$$

Note: the side condition in the λ-rule is there only for DETs.

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- Rules for truth of logical formulas

$$\frac{P : \mathbf{t} \quad Q : \mathbf{t}}{P \supset Q : \mathbf{t}} \qquad \frac{Q\ true\ [P\ true]}{P \supset Q\ true} \qquad \frac{P \supset Q\ true \quad P\ true}{Q\ true}$$

$$\frac{A\ type \quad P : \mathbf{t}\ [x : A]}{\forall(A, x.P) : \mathbf{t}} \qquad \frac{P\ true\ [x : A]}{\forall(A, x.P)\ true} \qquad \frac{\forall(A, x.P[x])\ true \quad a : A}{P[a]\ true}$$

- Rule for "conversion" of logical formulas (λ-conversion omitted)

$$\frac{P\ true \quad Q : \mathbf{t}}{Q\ true} \quad (P \simeq Q)$$

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Dependent event types in C_e

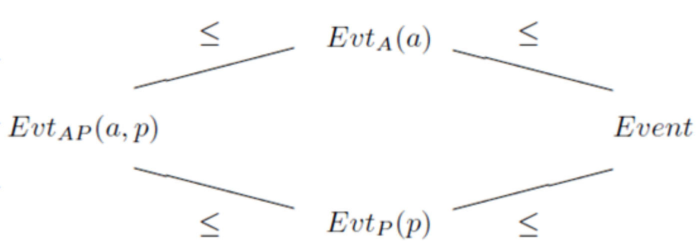
$$\frac{}{Agent\ type} \qquad \frac{}{Patient\ type}$$

$$\frac{}{Event\ type} \qquad \frac{a : Agent}{Evt_A(a)\ type} \qquad \frac{p : Patient}{Evt_P(p)\ type} \qquad \frac{a : Agent \quad p : Patient}{Evt_{AP}(a,p)\ type}$$

$$\frac{a : Agent \quad p : Patient}{Evt_{AP}(a,p) \leq Evt_A(a)} \qquad \frac{a : Agent \quad p : Patient}{Evt_{AP}(a,p) \leq Evt_P(p)} \qquad \frac{a : Agent}{Evt_A(a) \leq Event} \qquad \frac{p : Patient}{Evt_P(p) \leq Event}$$

$$\frac{A\ type}{A \leq A} \qquad \frac{A \leq B \quad B \leq C}{A \leq C} \qquad \frac{A' \leq A \quad B \leq B'}{A \to B \leq A' \to B'}$$

$$\frac{A \simeq B}{A \leq B} \qquad \frac{a : A \quad A \leq B}{a : B}$$



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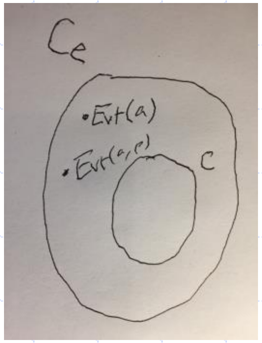
Conservativity

Background notes

(1) Conservative extension: "J in C and |- J in C_e, then |- J in C."

(2) Logical consistency is preserved by conservative extensions.



<u>Theorem</u>. C_e is a conservative extension over Church's simple type theory.

- <u>Proof</u>.
  - Define R : $C_e \rightarrow C$ that preserves derivations.
    - R maps Evt(…) to Event and Agent/Patient to **e**.
    - R(t)=t for $t \in C$.
  - For any C_e-derivation D, R(D) is a C-derivation.

<u>Corollary</u>. C_e is logically consistent.

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- Remark
  - Why meta-theory?
  - Any extension of an existing logical system need be shown to be "OK" (eg, still logically consistent).
  - Logical consistency is a most basic requirement for a foundational semantic language (either directly or indirectly).
- TTR, "Type Theory with Records", is not a type theory as usually understood: it is a set-theoretical system of notations.

DET-solution to EQP

(1) Nobody talked.

Neo-Davidsonian in Montague's setting (repeated):

(2) $\neg\exists x{:}\mathbf{e}.\ human(x)\ \&\ \exists v{:}Event.\ talk(v)\ \&\ agent(v,x)$

(3) $\exists v{:}Event.\ \neg\exists x{:}\mathbf{e}.\ human(x)\ \&\ talk(v)\ \&\ agent(v,x)$

The incorrect (3) is well-typed.

Dependent event types in Montague's setting:

(4) $\neg\exists x{:}\mathbf{e}.\ human(x)\ \&\ \exists v{:}Evt_A(x).\ talk(v)$

(#) $\exists v{:}Evt_A(x).\ \neg\exists x{:}\mathbf{e}.\ human(x)\ \&\ talk(v)$

where (#) is ill-typed since the first "x" is outside scope of "$\exists x{:}\mathbf{e}$".

Selectional restrictions with events

- (#) Tables talk.
  - Montague: $\forall x{:}\mathbf{e}.talk(x)$ – well-typed but false ($talk : \mathbf{e}\rightarrow\mathbf{t}$)
  - MTT-sem: $\forall x{:}Table.talk(x)$ – ill-typed ($talk : Human\rightarrow Prop$)
- What happens when we have events? ($talk : Event\rightarrow\mathbf{t}/Prop$)
  - Montague: $\forall x{:}\mathbf{e}\ \exists v{:}Event.\ talk(v)\ \&\ agent(v)=x$ (well-typed)
  - MTT-sem: $\forall x{:}Table\ \exists v{:}Evt_A(x).\ talk(v)$

    where we have $Table \leq Agent$. (Also well-typed!)

So? There are three approaches to enforce selectional restriction with events:

1. Refining typing for verb phrases (like talk)
2. Refining typing of thematic roles (like agent)
3. Further refining dependent event types by subtyping

- Approach 1: Instead of (neo-Davidsonian) talk : Event→**t**,
  - $talk_h$: Human→Event→Prop (Davidson's original proposal), or
  - $talk_d$: ∏h:Human. Evt_A(h)→Prop (dependent typing)

  Then, "Tables talk" is ill-typed – table x is not a human:
  - (#) ∀x:Table ∃v:Event. $talk_h$(x,v) & agent(v)=x
  - (#) ∀x:Table ∃v:Evt_A(x). $talk_d$(x,v)
- Approach 2: Instead of (neo-Davidsonian) agent:Event→**e**,
  - $agent_h$: Event→Human (with codomain being Human)

  Then, "Tables talk" is ill-typed – table x is not a human:
  - (#) ∀x:Table ∃v:Event. talk(v) & $agent_h$(v)=x

- Approach 3: refined DETs
  - Let $T \leq_c$ Agent. (Consider subtypes of Agent, wlg.)
    - $Evt_A[T] : T \rightarrow Type$
    - $Evt_A[T](a) = Evt_A(c(a))$, for any $a : T$.
- Examples
  - Men talk.
    - $\forall x{:}Man\ \exists v{:}Evt_A[Human](x).\ talk(v)$ (OK because $Man \leq Human$)
  - Tables talk.
    - (#) $\forall x{:}Table\ \exists v{:}Evt_A[Human](x).\ talk(v)$ (ill-typed - x is not a human.)
  - John picked up and mastered the book.
    - $\exists v{:}Evt_{AP}[Human, P\bullet I](j,b).\ pick\text{-}up(v) \& master(v)$, where $b : Book \leq P\bullet I$.
- Note: this approach is more flexible/powerful.