A theory of events and situations

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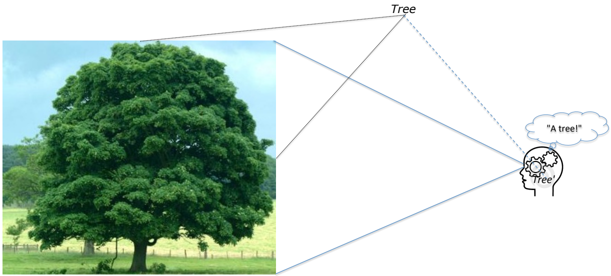
Type theory with records for natural language semantics,
NASSLLI 2012
Lecture 1, part 2

Outline

Outline

Seeing a tree (a simulation view)



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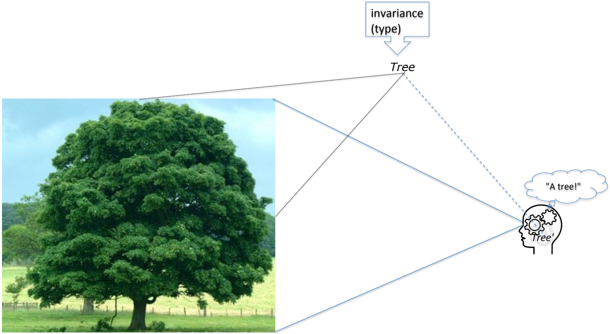

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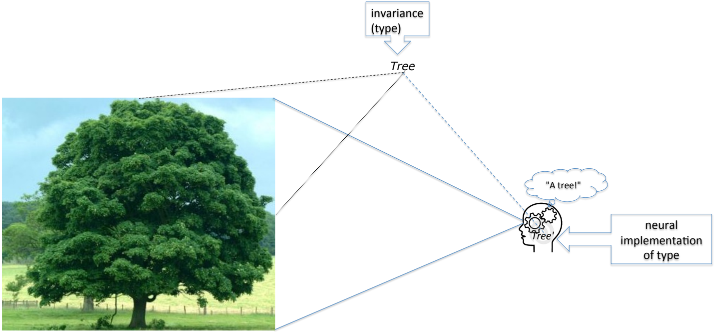

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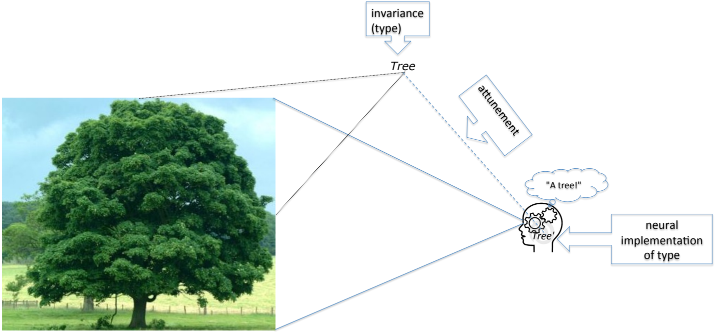

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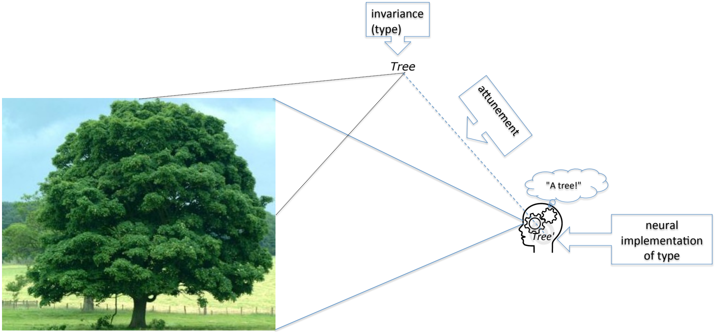


Gibson (1986); Barwise and Perry (1983)

Judgement

- (An agent judges that) object a is of type T.
- $a : T$

Outline

TTR: Type theory with records

- The most recent published reference for the details is Cooper (2012)
- Also Cooper (2005a) for an earlier detailed treatment
- Cooper (2005b) for relation to various semantic theories
- `https://sites.google.com/site/typetheorywithrecords/drafts/ch1-draft111114.pdf` for some current work in progress we will discuss here

Basic types

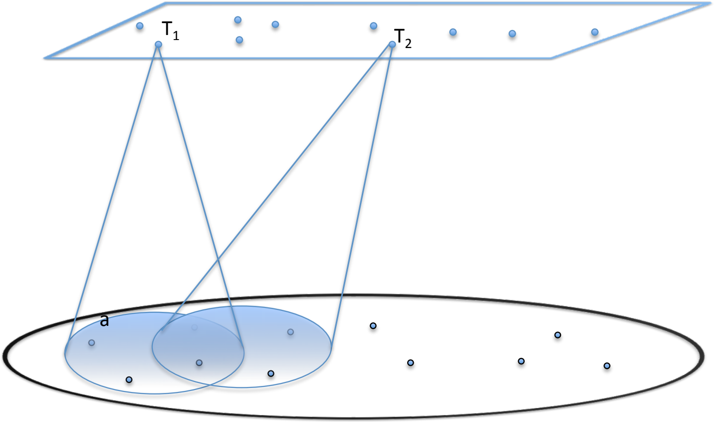
A *system of basic types* is a pair:

$$\mathbf{TYPE}_B = \langle \mathbf{Type}, A \rangle$$

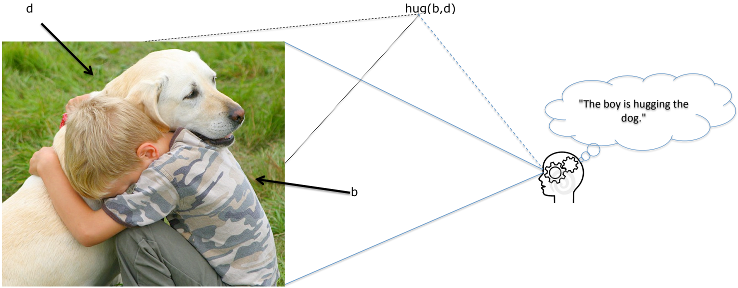
where:

1. **Type** is a non-empty set
2. A is a function whose domain is **Type**
3. for any $T \in \mathbf{Type}$, $A(T)$ is a set disjoint from **Type**
4. for any $T \in \mathbf{Type}$, $a :_{\mathbf{TYPE_B}} T$ iff $a \in A(T)$

$a : T_1$



Seeing a hugging event



Predicate signatures

A *predicate signature* is a triple

$$\langle \textbf{Pred}, \textbf{ArgIndices}, \mathit{Arity} \rangle$$

where:

1. **Pred** is a set (of predicates)
2. **ArgIndices** is a set (of indices for predicate arguments, normally types)
3. *Arity* is a function with domain **Pred** and range included in the set of finite sequences of members of **ArgIndices**.

Polymorphic predicate signatures

A *polymorphic predicate signature* is a pair

$$\langle \mathbf{Pred}, \mathbf{ArgIndices}, \mathit{Arity} \rangle$$

where:

1. **Pred** is a set (of predicates)
2. **ArgIndices** is a set (of indices for predicate arguments, normally types)
3. *Arity* is a function with domain **Pred** and range included in the powerset of the set of finite sequences of members of **ArgIndices**.

Complex types

A *system of complex types* is a quadruple:

$$\textbf{TYPE}_C = \langle \textbf{Type}, \textbf{BType}, \langle \textbf{PType}, \textbf{Pred}, \textbf{ArgIndices}, Arity \rangle, \langle A, F \rangle \rangle$$

where:

1. $\langle \textbf{BType}, A \rangle$ is a system of basic types
2. $\textbf{BType} \subseteq \textbf{Type}$
3. for any $T \in \textbf{Type}$, if $a :_{\langle \textbf{BType}, A \rangle} T$ then $a :_{\textbf{TYPE}_\textbf{C}} T$
4. $\langle \textbf{Pred}, \textbf{ArgIndices}, Arity \rangle$ is a (polymorphic) predicate signature
5. If $P \in \textbf{Pred}$, $T_1 \in \textbf{Type}, \ldots, T_n \in \textbf{Type}$, $Arity(P) = \langle T_1, \ldots, T_n \rangle$ ($\langle T_1, \ldots, T_n \rangle \in Arity(P)$) and $a_1 :_{\textbf{TYPE}_\textbf{C}} T_1, \ldots, a_n :_{\textbf{TYPE}_\textbf{C}} T_n$ then $P(a_1, \ldots a_n) \in \textbf{PType}$
6. $\textbf{PType} \subseteq \textbf{Type}$
7. for any $T \in \textbf{PType}$, $F(T)$ is a set disjoint from $\textbf{Type}$
8. for any $T \in \textbf{PType}$, $a :_{\textbf{TYPE}_\textbf{C}} T$ iff $a \in F(T)$

A boy hugs a dog

$$\left[\begin{array}{lll} \text{e-time} & : & \mathit{Time} \\ \text{x} & : & \mathit{Ind} \\ \text{c}_{\text{boy}} & : & \text{boy(x,e-time)} \\ \text{y} & : & \mathit{Ind} \\ \text{c}_{\text{dog}} & : & \text{dog(y,e-time)} \\ \text{c}_{\text{hug}} & : & \text{hug(x,y,e-time)} \end{array}\right]$$

The official notation

$$\left[\begin{array}{lll} \text{e-time} & : & \mathit{Time} \\ \text{x} & : & \mathit{Ind} \\ \text{c}_{\text{boy}} & : & \langle \lambda v : \mathit{Ind}(\lambda t : \mathit{Time}(\text{boy}(v,t))), \langle \text{x},\text{e-time}\rangle\rangle, \\ \text{y} & : & \mathit{Ind} \\ \text{c}_{\text{dog}} & : & \langle \lambda v : \mathit{Ind}(\lambda t : \mathit{Time}(\text{dog}(v,t))), \langle \text{y},\text{e-time}\rangle\rangle \\ \text{c}_{\text{hug}} & : & \langle \lambda v_1 : \mathit{Ind}(\lambda v_2 : \mathit{Ind}(\lambda t : \mathit{Time}(\text{hug}(v_1,v_2,t)))), \\ & & \quad \langle \text{x},\text{y},\text{e-time}\rangle\rangle \end{array}\right]$$

Function types

$\mathbf{TYPE}_C$ *has function types* if

1. for any $T_1, T_2 \in \mathbf{Type}$, $(T_1 \rightarrow T_2) \in \mathbf{Type}$
2. for any $T_1, T_2 \in \mathbf{Type}$, $f :_{\mathbf{TYPE_C}} (T_1 \rightarrow T_2)$ iff f is a function whose domain is $\{a \mid a :_{\mathbf{TYPE_C}} T_1\}$ and whose range is included in $\{a \mid a :_{\mathbf{TYPE_C}} T_2\}$

Records

- A *record* is a finite set of ordered pairs (called *fields*) which is the graph of a function. If r is a record and $\langle \ell, v \rangle$ is a field in r we call ℓ a *label* and v a *value* in r and we use $r.\ell$ to denote v. $r.\ell$ is called a *path* in r. If π is a path in r whose denotation is itself a record with a label ℓ, then $\pi.\ell$ is also a path in r.

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- A record r is *well-typed* with respect to a system of types **TYPE** with set of types **Type** and a set of labels L iff for each field $\langle \ell, a \rangle \in r$, $\ell \in L$ and $a :_{\mathbf{TYPE}} T$ for some $T \in \mathbf{Type}$.

Record types I

A system of complex types $\textbf{TYPE}_C = \langle\textbf{Type}, \textbf{BType}, \langle\textbf{PType}, \textbf{Pred}, \textbf{ArgIndices}, \mathit{Arity}\rangle, \langle A, F\rangle\rangle$ *has record types based on* $\langle L, \textbf{RType}\rangle$, where L is a countably infinite set (of labels) and $\textbf{RType} \subseteq \textbf{Type}$, defined by:

1. $\mathit{Rec} \in \textbf{RType}$
2. $r :_{\textbf{Type}_C} \mathit{Rec}$ iff r is a well-typed record with respect to $\textbf{TYPE}_C$ and L.
3. if $\ell \in L$ and $T \in \textbf{Type}$, then $\{\langle\ell, T\rangle\} \in \textbf{RType}$.
4. $r :_{\textbf{Type}_C} \{\langle\ell, T\rangle\}$ iff $r :_{\textbf{Type}_C} \mathit{Rec}$, $\langle\ell, a\rangle \in r$ and $a :_{\textbf{Type}_C} T$.
5. if $R \in \textbf{RType}$, $\ell \in L$, ℓ does not occur as a label in R (i.e. there is no field $\langle\ell', T'\rangle$ in R such that $\ell' = \ell$), then $R \cup \{\langle\ell, T\rangle\} \in \textbf{RType}$.

Record types II

6. $r :_{\mathbf{Type}_C} R \cup \{\langle \ell, T\rangle\}$ iff $r :_{\mathbf{Type}_C} R$, $\langle \ell, a\rangle \in r$ and $a :_{\mathbf{Type}_C} T$.
7. if R is a member of **RType**, $\ell \in L$ not occurring as a label in R, $T_1, \ldots, T_m \in \mathbf{Type}$, $R.\pi_1, \ldots, R.\pi_m$ are paths in R and $\mathcal{F}$ is a function of type $((a_1 : T_1) \to \ldots \to ((a_m : T_m) \to Type)\ldots)$, then $R \cup \{\langle \ell, \langle \mathcal{F}, \langle \pi_1, \ldots, \pi_m\rangle\rangle\rangle\} \in \mathbf{RType}$.
8. $r :_{\mathbf{TYPE}_C} R \cup \{\langle \ell, \langle \mathcal{F}, \langle \pi_1, \ldots, \pi_m\rangle\rangle\rangle\}$ iff $r :_{\mathbf{TYPE}_C} R$, $\langle \ell, a\rangle$ is a field in r, $r.\pi_1 :_{\mathbf{TYPE}_C} T_1, \ldots, r.\pi_m :_{\mathbf{TYPE}_C} T_m$ and $a :_{\mathbf{TYPE}_C} \mathcal{F}(r.\pi_1, \ldots, r.\pi_m)$.

The type *Type*

- The previous slide introduced the type *Type*
- T : *Type* iff $T \in$ **Type**

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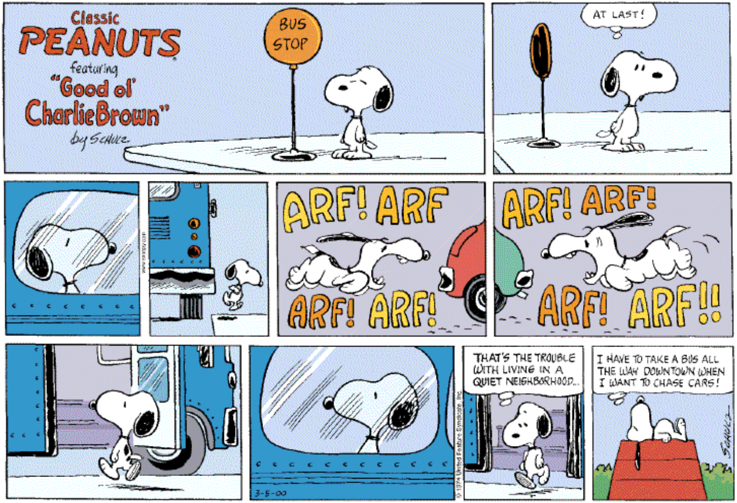
- $T : Type$ iff $T \in \mathbf{Type}$
- $Type \in \mathbf{Type}$
- $Type : Type$
- But suppose we allow some type to have the extension $\{T \in \mathbf{Type} \mid T \not: T\}$ ...

The type *Type*

- The previous slide introduced the type *Type*
- T : *Type* iff $T \in \mathbf{Type}$
- *Type* $\in \mathbf{Type}$
- *Type*: *Type*
- But suppose we allow some type to have the extension $\{T \in \mathbf{Type} \mid T \not: T\} \ldots$
- This leads us to stratification.

Outline

Fernando's string theory



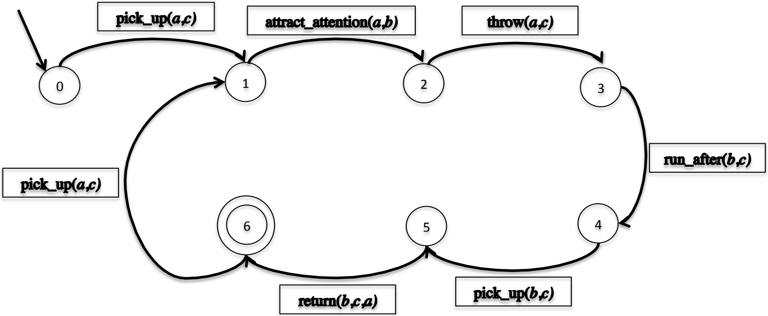
Some references to Fernando's work

Fernando (2004, 2006, 2008, 2009)

Regular types

1. if T_1, $T_2 \in$ **Type**, then $T_1 ⁀ T_2 \in$ **Type**
   $a : T_1 ⁀ T_2$ iff $a = x ⁀ y$, $x : T_1$ and $y : T_2$
2. if $T \in$ **Type** then $T^+ \in$ **Type**.
   $a : T^+$ iff $a = x_1 ⁀ \ldots ⁀ x_n$, $n > 0$ and for i, $1 \leq i \leq n$, $x_i : T$
   ...

A game of fetch



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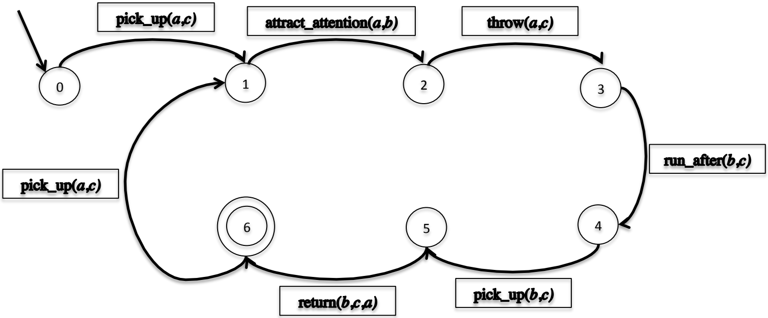

$$(\text{pick\_up}(a,c)^\frown\text{attract\_attention}(a,b)^\frown\text{throw}(a,c)^\frown\text{run\_after}(b,c)^\frown \text{pick\_up}(b,c)^\frown\text{return}(b,c,a))^+$$

Getting serious about time: intervals

$$\left[\begin{array}{lcl} \text{start} & : & \mathit{Time} \\ \text{end} & : & \mathit{Time} \\ \text{c}_{<} & : & \text{start}<\text{end} \end{array}\right]$$

Getting serious about time: the fetch-game type

$$
(\begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{pick\_up}}:\text{pick\_up}(a,c,\text{e-time})\end{bmatrix}{}^\frown{}_< \begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{att\_att}}:\text{attract\_attent}(a,b,\text{e-time})\end{bmatrix}{}^\frown{}_<
$$

$$
\begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{throw}}:\text{throw}(a,c,\text{e-time})\end{bmatrix}{}^\frown{}_< \begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{run\_after}}:\text{run\_after}(b,c,\text{e-time})\end{bmatrix}{}^\frown{}_<
$$

$$
\begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{pick\_up}}:\text{pick\_up}(b,c,\text{e-time})\end{bmatrix}{}^\frown{}_< \begin{bmatrix}\text{e-time}:\mathit{TimeInt}\\ \text{c}_{\text{return}}:\text{return}(b,c,a,\text{e-time})\end{bmatrix})^{+_<}
$$

Temporal concatenation

1. If T_1 and T_2 are subtypes of $\left[\text{e-time}{:}\,\mathit{TimeInt}\right]^+$ then $T_1{}^{\frown<}T_2$ is a type.
2. $a : T_1{}^{\frown<}T_2$ iff $a = a_1{}^{\frown}a_2$, $a_1 : T_1$, $a_2 : T_2$ and last(a_1).e-time.end<first(a_2).e-time.start

Temporal Kleene-$+$

1. If T is a subtype of $\left[\text{e-time}: \mathit{TimeInt}\right]$ then $T^{+<}$ is a type
2. $a : T^{+<}$ iff $a = x_1{}^\frown \ldots {}^\frown x_n$, $n > 0$ and for i, j, $1 \leq i < j \leq n$, $x_i : T$, $x_j : T$ and $x_i{}^\frown x_j : T^{\frown <} T$

Outline

Partiality of event perception

- Do not need to observe all the frames in an event
- Suffices to observe enough to uniquely identify event types agent has in its resources

Inferring an event type from a partial observation

$$\lambda r{:}\left[\begin{array}{l}\mathrm{x}{:}\,\mathit{Ind}\\ \mathrm{c}_{\mathrm{human}}{:}\mathrm{human}(\mathrm{x})\\ \mathrm{y}{:}\,\mathit{Ind}\\ \mathrm{c}_{\mathrm{dog}}{:}\mathrm{dog}(\mathrm{y})\\ \mathrm{z}{:}\,\mathit{Ind}\\ \mathrm{c}_{\mathrm{stick}}{:}\mathrm{stick}(\mathrm{z})\\ \text{e-time}{:}\,\mathit{TimeInt}\\ \mathrm{e}{:}\left[\begin{array}{l}\text{e-time}{:}\,\mathit{TimeInt}\\ \mathrm{c}_{\leq}{:}\Uparrow\text{e-time.start}\leq\text{e-time.start}\\ \mathrm{c}_{\mathrm{pick\_up}}{:}\mathrm{pick\_up}(\Uparrow\mathrm{x},\Uparrow\mathrm{z},\text{e-time})\end{array}\right]^\frown{}^{<}\left[\begin{array}{l}\text{e-time}{:}\,\mathit{TimeInt}\\ \mathrm{c}_{\leq}{:}\text{e-time.start}\leq\Uparrow\text{e-time.start}\\ \mathrm{c}_{\mathrm{att\_att}}{:}\mathrm{att\_att}(\Uparrow\mathrm{x},\Uparrow\mathrm{y},\text{e-time})\end{array}\right]\end{array}\right]$$

$$\left(\left[\begin{array}{l}\text{e-time}{:}\,\mathit{TimeInt}\\ \mathrm{c}_{\leq}{:}r.\text{e-time.start}\leq\text{e-time.start}\\ \mathrm{e}{:}\mathrm{play\_fetch}(r.\mathrm{x},r.\mathrm{y},r.\mathrm{z},\text{e-time})\end{array}\right]\right)$$

Three views of this inference

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Three views of this inference

- function from objects (events) to a *type* – $\lambda a : T_1(T_2[a])$
- a *dependent type*
- perceiving something and inferring the type of something not (yet) perceived from that perception
- we will see a number of other uses of dependent types, for example as the interpretation of verb phrases

Outline

Summary

- Type theory as a formal theory related to perception
- A basic introduction to TTR
- Events as strings
- Partial observation of events and inference
- Frames in lexical semantics

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