On of syntax and semantics for voice assistants in autonomous vehicles

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14^{th} February 2022

Big Picture

Manifold Ideas

This project contains bits and pieces of :

1. Functional Programming languages : GF (Grammatical Framework), Haskell, Theorem Provers (Agda, Coq, ...)
2. Verification for Robotics Systems : Temporal logic (mostly at the syntactic level, for now)
3. Natural Language Processing : Semantic Parsing, Controlled Natural Languages

```
data Nat : Set where
  zero : Nat
  suc : Nat -> Nat
```

```
open import F

plus : Nat → Nat → Nat
plus zero b = b
plus (suc a) b = suc (plus a b)
```

This project is quite multifaceted, still in a somewhat primordial state (and therefore may be taken in many directions).

Goal : Design a controlled natural language which is

- Suitable as an "approximation" for a voice assistant for an autonomous vehicle
- Has a well defined semantics in temporal logic
- Seeking to balance breadth and depth of our system

Trade-offs

- Breadth : Wide coverage, usable by non-experts (where ML comes in)
- Depth : Well-behaved, verifiable (where FP comes in)

Ideal Pipeline

$$
\begin{aligned}
\text{Utterance} &\xrightarrow{Speech\ Recognizer} \text{String} \\
&\xrightarrow{Canonicalization_{BERT}} \text{String} \\
&\xrightarrow{Parsing\ (GF)} \text{Abstract Syntax Tree (NL)} \\
&\xrightarrow{[\![-]\!]_{Haskell}} \text{Abstract Syntax Tree (LTL)} \\
&\xrightarrow{\vDash} \text{Verifiable Path}
\end{aligned}
\tag{1}
$$

What we have so far...

$$\begin{aligned} \text{String} &\xrightarrow{Parsing\ (GF)} \text{Abstract Syntax Tree (NL)} \\ &\xrightarrow{[\![-]\!]_{Haskell}} \text{Abstract Syntax Tree (LTL)} \\ &\xrightarrow[Agda]{\models} \text{“Standard Semantics”} \end{aligned} \tag{2}$$

Example AST

"go to the store and turn left" ↦

```
CompoundCommand
    * And
      BasePosCommand
        * SimpleCom
            * ModAction
                * Go
                  MkAdvPh
                    * To
                      WhichObject
                        * The
                          Store
        SimpleCom
          * ModAction
              * Turn
                WherePhrase (Left)
```

Example Cont..

$[\![$“go to the store and turn left . Finish .”$_{AST}]\!]_{Haskell}$

```
F
  (Meet
    (Atom "the_store")
    (X
      (Meet
        (Atom "left")
        (G (Atom "FINISHED")))))
```

Interpretation

Eventually be in a state where you are at the store. Directly after, you are in a state where you are left. From thereon, you are forever finished.

Functional Programming

Types, and type-checking is a fundamental way to seperate the process of programming into two phases

- Static : Specification, Types
- Dynamic : Implentation, Programs

- Correct-by-construction mentality - “verification technique”
- Constraints are baked into user-defined types.
- Specification guides implementation. Functional programmers spend almost all their time thinking about types.
- Focus energy on high-level (abstract) details
- It is convenient to implement programming languages (i.e. write interpreters and compilers)

Grammatical Framework

- Functional programming language
- Implementing natural language parsers and linearizes
- Separation of abstract syntax and concrete syntax.
- Intended for translation, multilingual support
- One designs a grammar, Parallel Multiple CFGs (PMCFG)
- Chomsky Hierarchy : CFG $<$ PMCFG $<$ Context Sensitive Grammar
- Standard Libarary : Resource Grammar Library (RGL)
- Embedding in Haskell : Portable Grammar Format (PGF)

GF Example

BNFC (traditional treatment of fixity)

```
Lam. Exp  ::= "\\" [PTele] "->" Exp ;
App. Exp2 ::= Exp2 Exp3 ;
```

Abstract :

```
fun
  Lam : [Tele] -> Exp -> Exp ;
  App : Exp -> Exp -> Exp ;
```

Concrete :

```
lin
  Lam pt e = mkPrec 0 ("\\" ++ pt ++ "->" ++ usePrec 0 e) ;
  App = infixl 2 "" ;
```

Haskell and Agda

Haskell

- One of the main FP languages - deep ties in Scotland and Sweden
- GADTs and pattern matching make for first-class tree transformations
- Defining and reasoning about logics and programming languages

Agda

- "Dependently typed Haskell"
- Interactive Theorem Prover
- Programs as proofs, propositions as types

Linear Temporal Logic

- Modal logic (temporal modality)
- Allows one to reason about sequential actions
- Verification for robotics systems
- Objective in reinforcement learning
- Other temporal logics (Signal TL, Computation Tree Logic, ...)
- Decidable

Complexity (and expressivity)

Propositional Logic $<$ Temporal Logic $<_{undecidable}$ First Order Logic

Temporal Operators

- $X\phi$: in the next state, phi holds
- $\diamond\phi$: exists a future state such that ϕ holds $(F\phi)$
- $\Box\phi$: ϕ holds for every future state $(G\phi)$

Where does ML come in?

Language Models

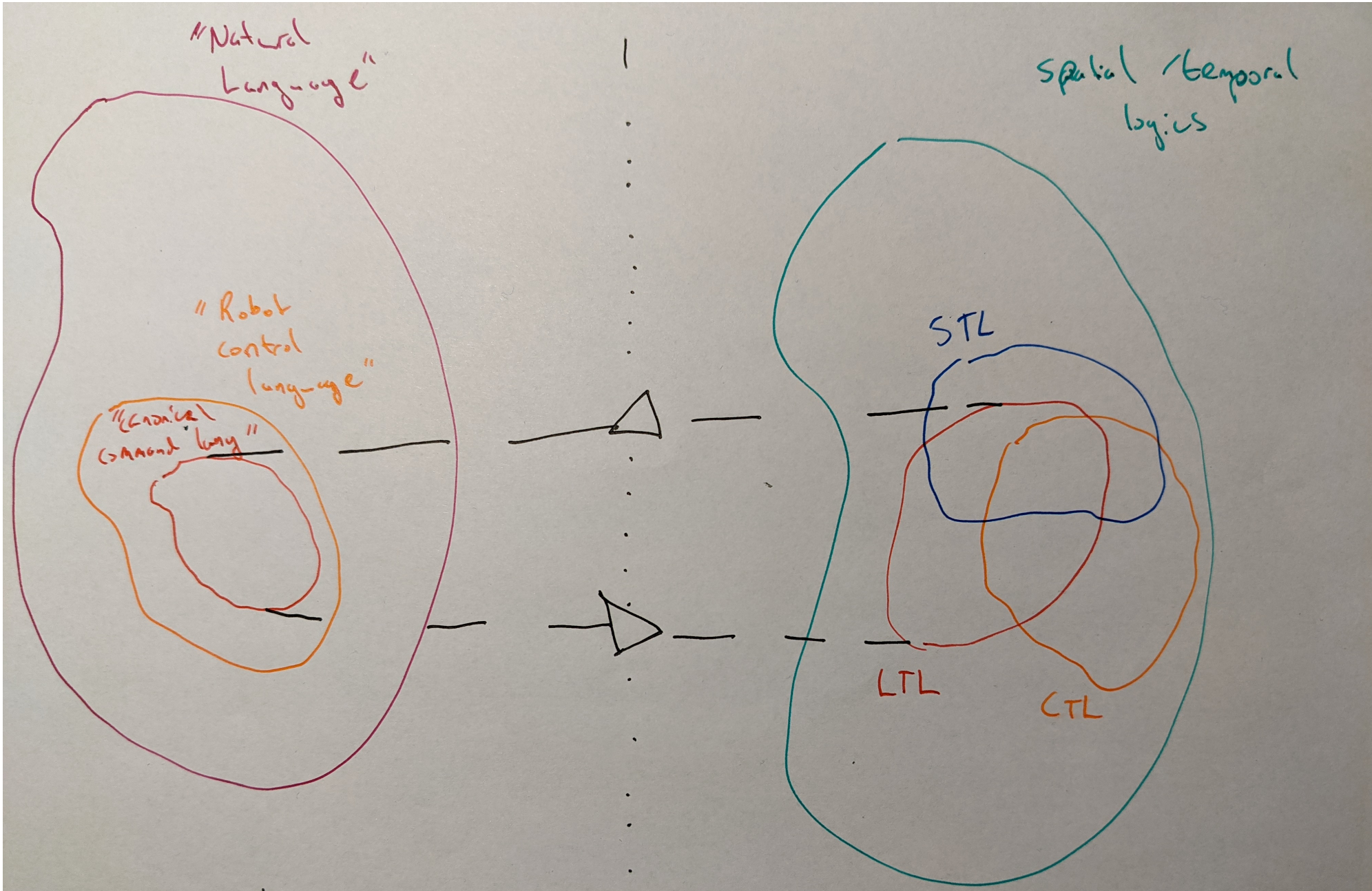
- Foundation models - future of NLP?
- BERT, GPT3, ...
- Pretrain and then fine-tune

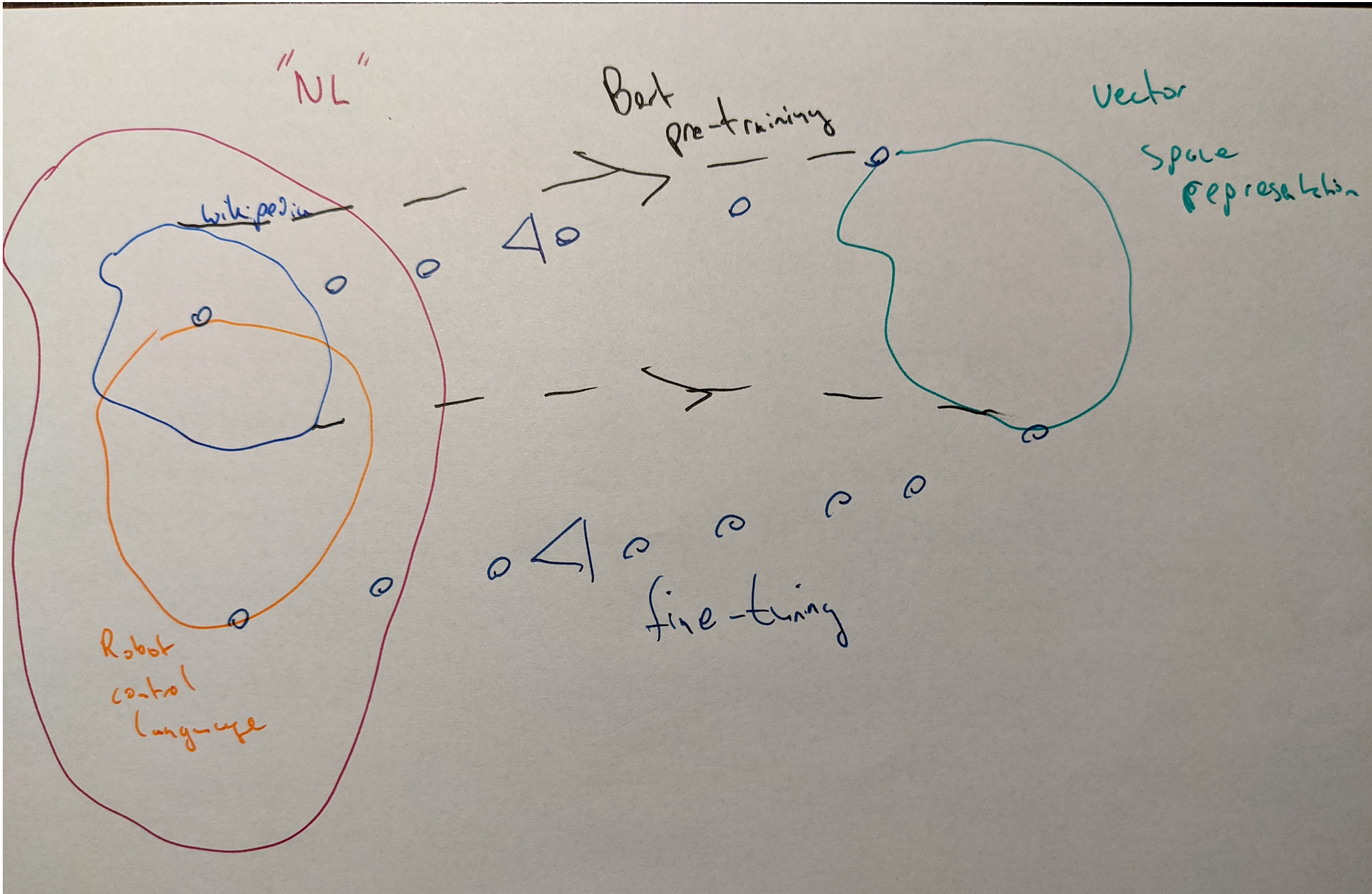
Ingredients

- Semantic Parser : NL Utterance -> Formal Language form
- Touchdown Data Set : 13000 sequences
- Few-shot semantic parsers paper (Microsoft Research) - open source Pytorch code

Idea

Integrate their technique and code with our parser and dataset


"Natural Language"
"Robot control language"
"Logical Command language"
Spatial / temporal logics
STL
LTL
CTL


"NL"
Bert
pre-training
Vector
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Robot
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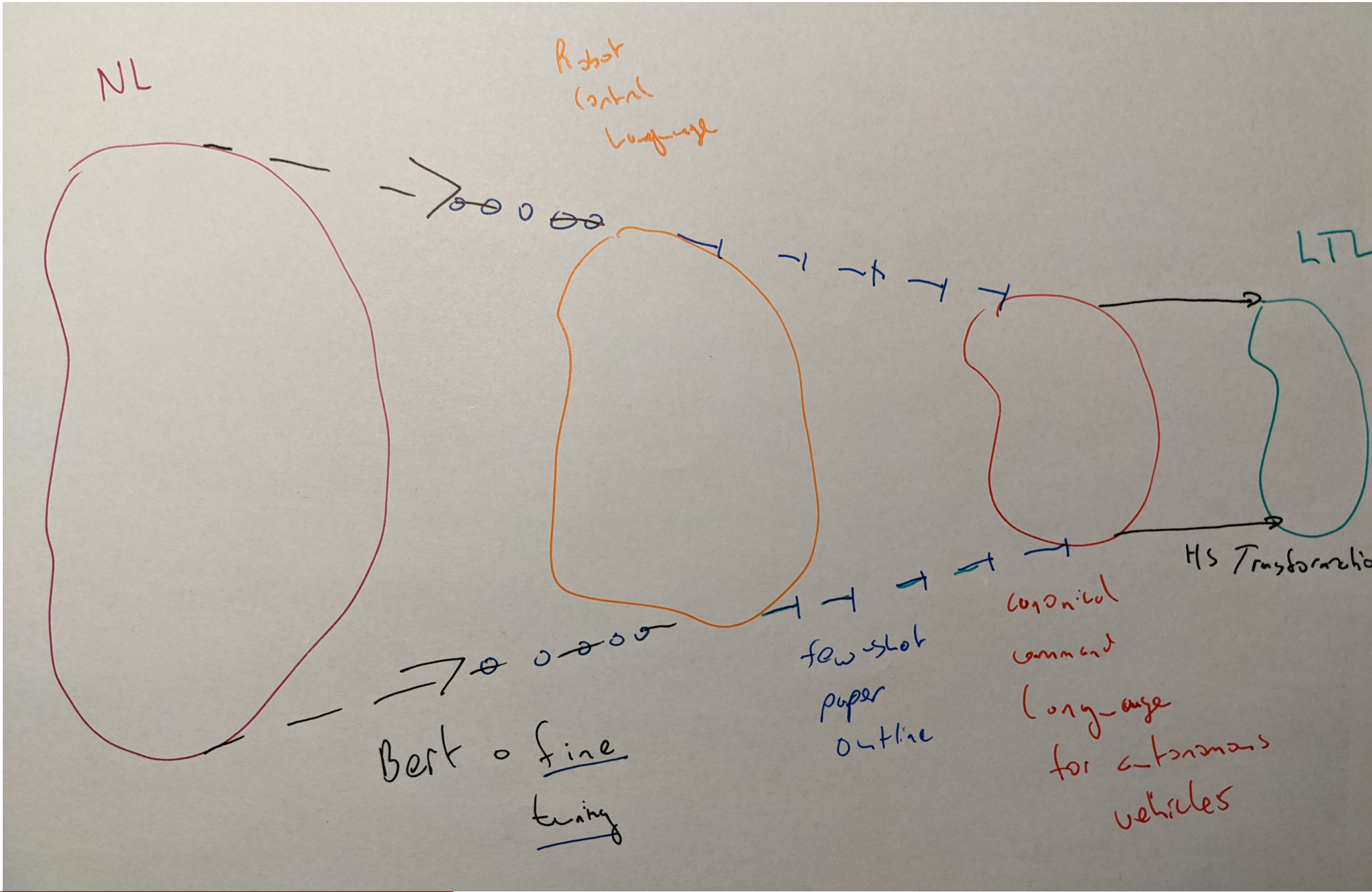
NL
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Control
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Future

- Expand parser itself
- Work on semantics , more expressive logic, etc
- Ground semantics to Touchdown location map
- Better data set?
- Working on a draft document, with references, of everything shown here.