On the syntax and semantics of voice assistants in autonomous vehicles

Warrick Macmillan

6^{th} May 2022

```
data ϕ : Set where
  atom    : Atom → ϕ
  ⊥ ⊤     : ϕ
  ¬_      : ϕ → ϕ
  _∨_ _∧_ _⇒_ : ϕ → ϕ → ϕ
  X F G : ϕ → ϕ
  _U_ _W_ _R_ : ϕ → ϕ → ϕ
```

```
record M (Atom : Set) : Set1 where
  field
    State : Set
    _↪_ : rel State
    relSteps : relAlwaysSteps _↪_
    L : State → Atom → Set
    -- L'' : Decidable L'
```

mutual

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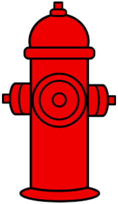

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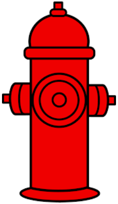

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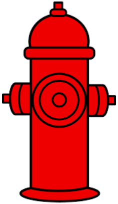

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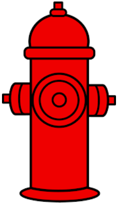

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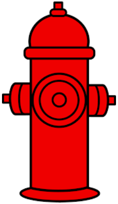

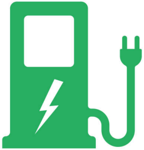

Ambiguities

"Go into the other lane"

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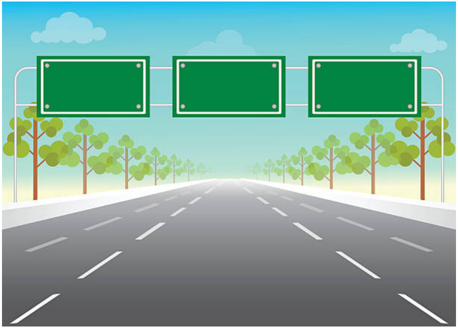

Ambiguities (cont.)

"Drive to the person with the dog"

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Simplified Autonomous Vehicle

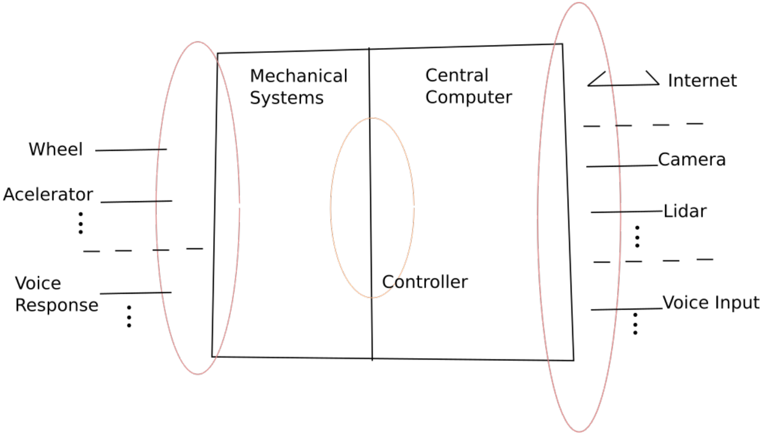

Figure: Self-driving car

Path

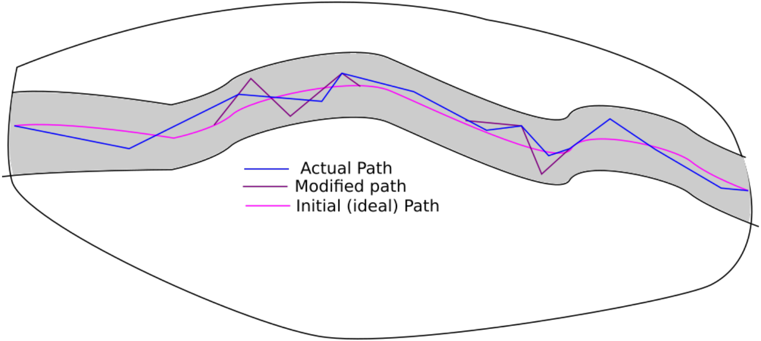

Figure: Initial, modified, and actual paths/routes

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- physical objects in the case of paths in Euclidean space

Verification Spectrum

Single Example	Set of Examples	Single Property	Metaproperty
Unit Testing	Property-based Testing	Model Checking	ITP

Verifiability

FP

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- Verification of system is can similarly be broken into sub-verifications

More Specifically

This project contains bits and pieces of :

1. Functional Programming Languages : GF (Grammatical Framework), Haskell, Agda
2. Natural Language Processing : Semantic Parsing, Controlled Natural Languages
3. Tools : Grammars, Decidable logics for motion planning and verification

Ideal Pipeline

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

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- Separation of abstract (semantic and syntactic) and concrete (syntactic and morphological) considerations

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TOUCHDOWN Dataset

```
([(["Go"],5527),(["be"],5300),(["turn"],4154),(["Turn"],4154)],["VB"])
([(["left"],228),(["came"],59),(["made"],47),(["started"],44)],["VBD"])
([(["going"],1684),(["facing"],939),(["moving"],849),(["passing"],617)],["V
([(["left"],1733),(["parked"],616),(["painted"],307),(["fenced"],263)],["VB
([(["are"],3554),(["'re"],1185),(["reach"],1100),(["get"],770)],["VBP"])
([(["is"],4919),(["has"],795),(["'s"],471),(["ends"],93)],["VBZ"])
```

n-grams : the 9-gram “so you are moving with the flow of traffic” occurs 311

Ontological Categories

```
cat
  PosCommand    ; -- go to the store
  Place         ; -- the store
  Time          ; -- in 5 minutes
  Action        ; -- drive
  Way           ; -- to
  How           ; -- quickly
  Where         ; -- left
  AdvPh         ; -- to the store
  UndetObj      ; -- store
  Determ        ; -- the
  Object        ; -- the store
  Number        ; -- a
  Conjunct      ; -- and
  Condition     ; -- there is a museum
  Descript      ; -- big
```

GF Functions

```
fun
  -- Explicit Temporality
  DoTil     : Action -> Time -> PosCommand ; go in one minute

  -- Modified action
  ModAction : Action -> AdvPh -> Action ; -- go to the store

  -- Adverbial Phrases
  MkAdvPh     : Way   -> Object -> AdvPh ; -- to the store

  -- Noun Phrases
  WhichObject : Determ -> UndetObj -> Object ; -- the red dog

  -- Modified Noun
  ModObj : Descript -> UndetObj -> UndetObj ; -- black dog
```

Base Ingredients

These represent the tree leaves to be grounded!

```
fun
  Quickly : How       ;
  Left    : Where     ;
  To      : Way       ;
  After   : Way       ;
  Store   : UndetObj  ;
  Traffic : UndetObj  ;
  London  : Place     ;
  Drive   : Action    ;
  Turn    : Action    ;
  Big     : Descript  ;
  A       : Determ    ;
```

go to the store, turn left and stop at the woman with the dog. go to the bridge. finish.

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        * CompoundCommand
            * And
              ConsPosCommand
                * SimpleCom
                    * ModAction
                        * Go
                          MkAdvPh
                            * To
                              WhichObject
                                * The
                                  Store
                  BasePosCommand
                    * SimpleCom
                        * ModAction
                            * Turn
                              WherePhrase
                                * Left
                      SimpleCom
                        * ModAction
                              Stop
                              MkAdvPh
                                * At
                                  WhichObject
                                    * The
                                      PhraseModObj
                                        * Woman
                                          MkAdjPh
                                            * With
                                              WhichObject
                                                * The
                                                  Dog
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Need a temporal until operator, U, to construct a semantically justifiable interpretation

Haskell LTL

go to the store, turn left and stop at the woman with the dog. go to the bridge. finish.

```
F (Meet
    (Atom "the_store")
    (F (Meet
        (Atom "turn_left")
        (F (Meet
             (Atom "the_woman_with_the_dog")
             (F (Meet
                  (Atom "the_bridge")
                  (G (Atom "FINISHED"))))))))
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semantics :: GListCommands -> Phi
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normalizeList ::  GListCommands -> GListCommands
  where
    normalizeNestedLists :: GListCommands -> GListPosCommand
      where
        normalizeListPosCommand :: GListPosCommand -> GListPosCommand
          where
            unSentence :: [GCommands] -> [GPosCommand]
            flattenSublist :: GPosCommand -> [GPosCommand]
            where
              getListPosCommands :: GListPosCommand -> [GPosCommand]
```

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 $(G\phi)$

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

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- Specificity and generality
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- Verifiability and validity

Where does ML come in?

Language Models

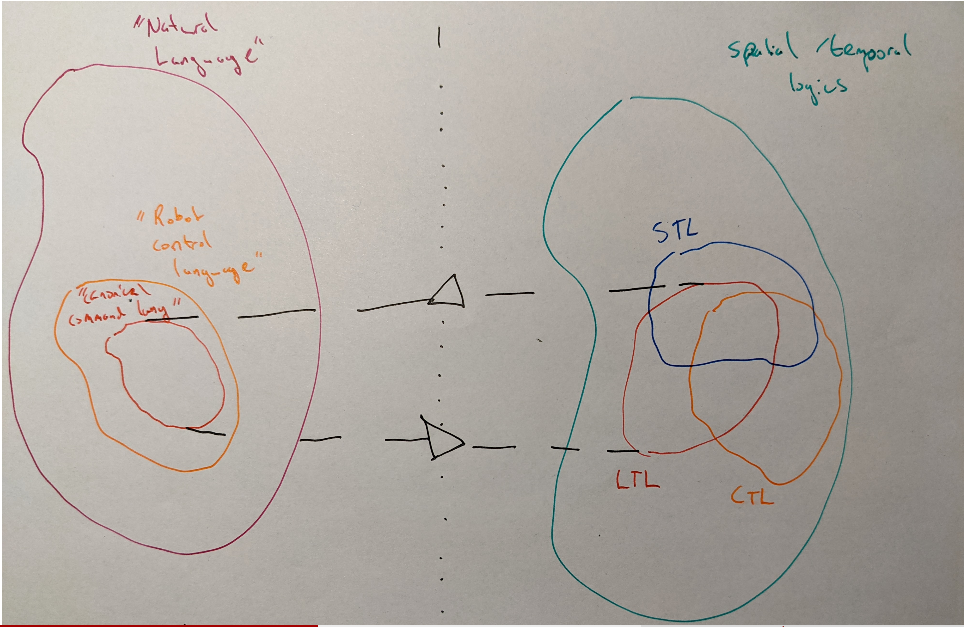
- Foundation models - future of NLP?
- BERT, GPT3, ...
- Pretrain and then fine-tune

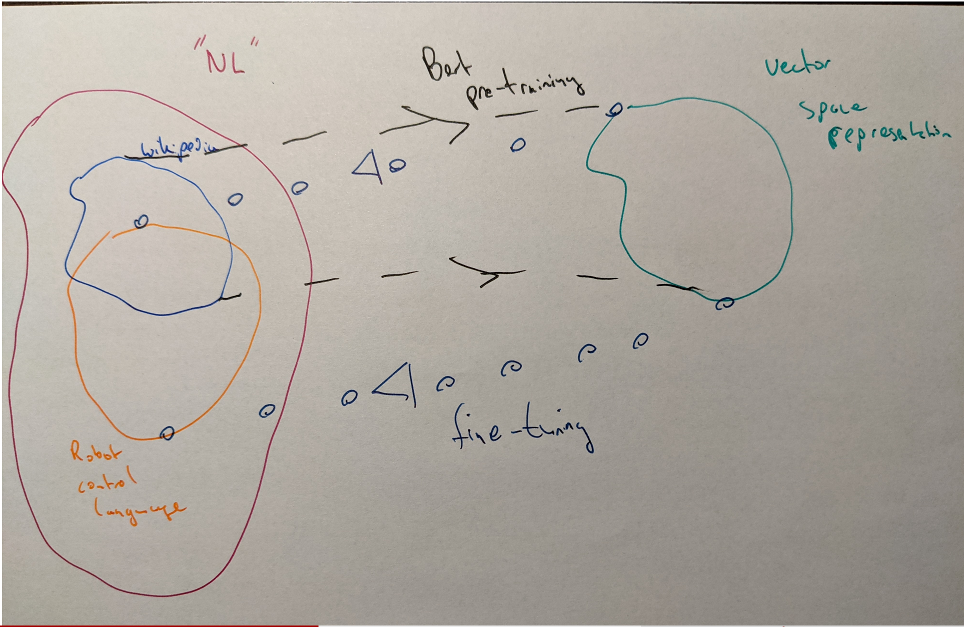
Ingredients

- 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"
"Canonical command lang"
Spatial / temporal logics
STL
LTL
CTL


"NL"
Bert
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Vector
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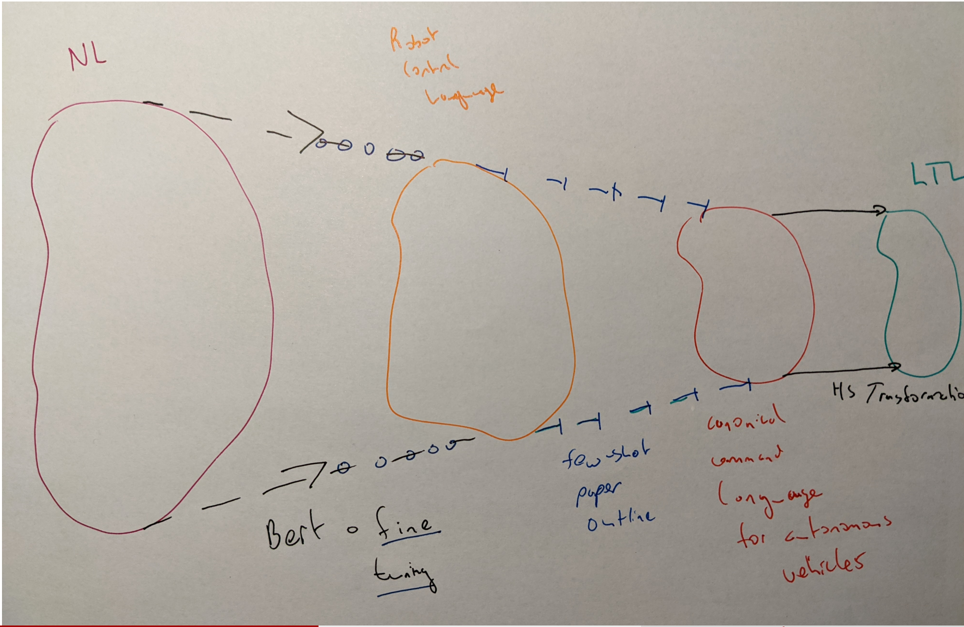
representation
wikipedia
Robot
control
language
fine-tuning


NL
Robot Control Language
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few shot paper outline
canonical command language for autonomous vehicles
HS Transformatio

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.

Acknolwedgements