Teaching Robots

Challenges to Decoding the Intention Behind Natural Instruction

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Outline

How human teach?
Natural Instruction
UAV Experiment results
Teaching by Touch
Conclusions
Why teaching robots?

Having robots capable of learning from natural instruction would allow us to train them for whatever we need.
Why teaching robots?

Tasks which require high-precision and risks.
Our goal: To construct robots which could learn from natural instruction

HOW HUMANS TEACH?
Imagine that you have to teach a child how to wash the dishes.
Natural instruction

While teaching another human, humans may provide

- Explicit definitions and examples of concepts, rules and conditions, i.e.

  This is a plate

  This is NOT a plate
Natural instruction

While teaching another human, humans may provide

• *Describe* and provide *demonstrations* of procedures.
  
  - *Take the plate*
  - *Take it to the sink*
  - *Put some soap on it*
  - *...and so on*
Natural instruction

While teaching another human, humans may provide

- Provide various kinds of feedback based on student behavior.

*Well done!*, *Awesome!*, *Well… it’s Ok*

*Not good*, *Hey, you stink!*
Natural instruction

While teaching another human, humans may provide

• Explicit definitions and examples of concepts, rules and conditions,
• *Describe* and provide *demonstrations* of procedures.
• Provide various kinds of *feedback* based on student behavior.

We refer to these patterns of instruction as *Natural Instruction Methods (NIMs)*.
Translate NIMs into ML algorithms

Natural Instruction Methods (NIMs) → Machine Learning Algorithms

- Teachers mix modes of interaction without notice
- Often instruction is implicit
- Precision
- Structure

Think about teaching washing the dishes
Then think about washing an apple
Traducing NIMs into MLs

Natural Instruction Methods (NIMs) \rightarrow \text{Machine Learning Algorithms}

Wash dishes:
Take the plate to the sink
Put some soap on it
Rub it
Pour some water

Concepts: Plate, Soap, Sink, Water

Wash dishes Procedure:
Take the plate to the sink...
Traducing NIMs into MLs

Natural Instruction Methods (NIMs) → Machine Learning Algorithms

Wash an apple:
- Take the apple to the sink
- Pour some water

Concepts: Apple
- Wash apple
- Procedure: Take the apple to the sink...
Automatic labeling/learning systems from Natural Instruction

Complete end-to-end system

Parsing of Teacher-Student Interactions

Concept

Procedure

Concept learner

Procedure learner

(Underlying Machine Learning algorithms)
Traducing NIMs into MLs

WAIT!

Both actions imply to WASH something. Then, if it is a plate, I should use soap. If it is an apple, I shouldn’t.

The teacher didn’t express this fact, but it was IMPLICIT.

Let’s assume that the teacher doesn’t teach the plate and apple concept before the procedure. Should the student imply those labels anyway?
So, Translating from NIMs into MLs may not be that easy after all.
Prior work

What do people do while teaching?
We conducted 3 experiments following a Wizard of Oz (WoZ) Setup

• Each teaching session consisted of a participant taking on the role of the Teacher while a researcher played the Student.

Teacher in room 1

Researcher in room 2

The Teacher was led to believe that he/she was interacting with an electronic student.
HOW HUMANS TEACH?

We made a study involving several experiments to solve these questions.

Wubble World

Charlie the robot
UAV Experiment
UAV Experiment

• Exploratory in nature
• Not human language involved
• Create commands using menu options
Teaching Task

2 Types of objects:
Fishing / Cargo boats

2 Sensors: Camera and Radiation sensor

Find Cargo Boats, Read radiation and generate a report.
Teacher Interface

Our Teacher Interface provides the facilities for:

- Procedure demonstration
- Object labeling
- Testing the student
- Provide Feedback in the form of happy or frowny faces.
Teaching by Demonstration

• The Teacher can label a sequence of actions as an example of a procedure.

5: TEACHER COMMAND: **Start** good example of procedure 'fly to boat'
6: TEACHER COMMAND: Fly plane to object/location @ latitude = 39.04, longitude = -122.80 (Object name = Boat12)
7: TEACHER COMMAND: Unpause the plane
11: SYSTEM ACTION: UAV's paused setting toggled
12: SYSTEM ACTION: Setting UAV's speed to 220.00 kts
...
25: TEACHER COMMAND: **End** example of procedure 'fly to boat'

We refer to this as the *Procedure Demonstration Facility*
Teaching Concepts by Example

The Teacher can define concepts (such as “cargo boat”) by selecting an object on the map interface and giving it a label.

12:12:32 Object @lat.=39.04, long.=-122.89 is a good example of object label ‘CargoBoat’ (Objectname=Boat11)

We refer to this as the Object Labeling Facility
Teaching by Reinforcement

The Teacher can give feedback to the Student, in the form of 1-3 “happy faces” or 1-3 “frowny faces”, issued at any time, and can also send a “You achieved goal <goal name>” message.

124: 69:94:228: TEACHER COMMAND: 1 happy face

165: 32:56:033: TEACHER COMMAND: You achieved goal 'find cargo boat'
Testing the Student

The Teacher can use simple commands that ask the Student to provide a label for an object or execute a previously defined procedure.

Perform procedure 'fly to boat' near specific location

Teacher: Which is the label of the object at this specific location?

Student: I don’t know

Teacher: That’s terribly wrong!
Human Teaching characteristics observed

- Extensive use of implicit instructions
- Teachers had problems delimiting procedures
- Teachers expect the student can understand the meaning of words
- Interleave Teaching, Testing and Feedback

- Teachers followed different styles while teaching
- A simple heuristic approach can cover most cases, but not all.
Transcripts Analysis

Is it possible to convert our transcripts into proper ML algorithm inputs?
Is it possible to convert our transcripts into proper ML algorithms inputs?
Human Labeling

• Two people analyzes all the transcripts
• Very labor intensive!
• Negotiated Vocabulary (set of labels)
Human Labeling

Instructions associated with teaching
(Procedure defs and Labeling)
  Implicit labeling
  Implicit Procedures
Goal definitions
Testing
Feedback
Our findings

• We found some teaching patterns, as
  • Teach-Test
  • Test – Feedback
  • Teaching – Test – Feedback

• Unexpected use of the Procedure Demonstration Facility

• Implicit teaching (Implicit Instructions)
• Ill-defined boundaries (Begin-End)
• Reliance on meaningful linguistic names for objects/Procedures
• Teachers followed different styles while teaching
Teaching Patterns

Teaching - Testing – Feedback Loop

35: 24 T: Start good example of procedure 'fly to cargo boat'
... 
159: 31:38 T: End example of procedure 'fly to cargo boat'
160: 31:48 T: Perform procedure 'fly to cargo boat' near
lat. 39.10, long. -122.82
...
164: 32:48 SR: Radiation sensor reading: high
165: 32:56 T: You achieved goal 'find cargo boat'
166: 32:59 T: 1 happy face

Start good example of procedure 'fly to cargo boat'
...
End example of procedure 'fly to cargo boat'
Perform procedure 'fly to cargo boat' near
Specific location
You achieved goal 'find cargo boat'
😊
Automatic labeling/learning systems from Natural Instruction

Parsing of Teacher-Student Interactions

- Concept
- Procedure
- Feedback

Concept learner
Procedure learner
Improve Learning

Concept learner
Procedure learner
Improve Learning

Concept learner
Procedure learner
Improve Learning
Multiple uses of the procedure demonstration facility

- 40% of teachers used the Procedure Demonstration facility in unexpected ways
Implicit Teaching

Decoding the intention behind instructions

Is HARD
Implicit Labeling

teachers maneuvered the UAV up to an object and then appeared to use the name of the object as the name of a procedure.

Start good example of procedure 'Cargo Boat'
Fly plane to object/location
Use camera to track object/location

End example of procedure 'Cargo Boat'
Implicit vs Explicit Labeling

Start good example of procedure 'Cargo Boat'
Fly plane to object/location
Use camera to track object/location
End example of procedure 'Cargo Boat'

How to find out without putting attention to the procedure name?

This object is a ‘Cargo Boat’

We must find a way to avoid language-interpretation.
Implicit Procedure Definition

Repetitive “orphan” blocks of commands across the transcripts. These commands didn’t belong to any procedure.

These blocks appear under certain conditions. For example, after approaching a boat:

- take a picture
- if it is a cargo boat
- read radiation.

It appears the teachers assumed the student was “paying attention” to these sequences and able to infer the boundaries between the implicit procedure definitions.
Ill-Defined Boundaries

The procedure was defined, but some key commands were not included on the definition

Fly plane to location
Turn on high resolution camera
Use camera to track object
(...UAV nearing destination...)

Start bad example of proc. 'Fly to cargo boat'
Unpause the plane
Pause the plane
(...UAV reached destination...)
End example of procedure 'Fly to cargo boat'
Challenges to interpreting Implicit teaching

Implicit teaching involves changes in the scene (maybe spatial)

The system must keep track of changes in state and properties of objects and automatically detect patterns
Automatic labeling/learning systems from Natural Instruction

Detect Concepts and Procedures (Explicit or Implicit)
Teacher Types

3 Teacher types based on organization of transcripts:

• Structured
• Semi-structured
• Free-Style
Structured Teachers

• Use the interface’s object labeling facility to teach object concepts
• The procedure demonstration facility to define procedures
• Test only on previous lessons
• No implicit object labeling
• Well-defined procedure's boundaries
Semi-Structured Teachers

- Test on previous lessons
- Explicit and Implicit labeling
- May or may not define procedures
Free-Style Teachers

- Testing before teaching
- Explicit and Implicit labeling
- Ill-defined Procedure Definitions

These teachers followed a more ‘natural’ way of interaction
Summary of Teaching Styles

The distribution of styles shows the need of handling unstructured teaching.

Semi-structured and Free Style teachers (82%) follow a more natural way of teaching:
- Opportunistic
- Not planned ahead
- Implicit teaching
Automatic Labeling
Script for automatic annotation

Following several rules based on heuristics followed by the human labelers for the original transcript-annotations

No use of inference or statistical techniques

Most of the labeling cases were covered, except for those involving implicit teaching.
Implicit teaching was found often across the transcripts. Almost all transcripts (except 2) contained some implicit procedure.

<table>
<thead>
<tr>
<th>Label</th>
<th>Labeling Heuristic</th>
<th>Script Successful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicit Object Label</td>
<td>Teaching command defining good or bad object example using the <em>object labeling construct</em></td>
<td>✓</td>
</tr>
<tr>
<td>Implicit Object Label</td>
<td>Teaching command defining good or bad object example using the <em>procedure construct</em></td>
<td>✗</td>
</tr>
<tr>
<td>Explicit Procedure Definition</td>
<td>Teaching command defining a procedure using the <em>procedure construct</em></td>
<td>✓</td>
</tr>
<tr>
<td>Implicit Procedure Definition</td>
<td>Repetition of similar set of action commands (camera track, take radiation reading or picture, generate report) in different scenario locations</td>
<td>✗</td>
</tr>
<tr>
<td>Test</td>
<td>Testing command (ask Student to perform a previously taught procedure or give the label of a world object)</td>
<td>✓</td>
</tr>
<tr>
<td>Feedback</td>
<td>Command evaluating Student's performance (1-3 happy or frowny faces)</td>
<td>✓</td>
</tr>
<tr>
<td>Goal Specification</td>
<td>Command labeling a goal that Student has achieved</td>
<td>✓</td>
</tr>
<tr>
<td>Setting Up for Teaching</td>
<td>All setup commands (change in location, speed, altitude or sensor settings) preceding a teaching command (object labeling or procedure definition)</td>
<td>✓</td>
</tr>
<tr>
<td>Setting Up for Testing</td>
<td>All setup commands preceding a testing command</td>
<td>✓</td>
</tr>
</tbody>
</table>
Teacher-Style Identification

The teacher-style determines the use of the interface.

The script was able to correctly identify all of the teachers who followed the structured teaching style.

Semi-structured vs. freestyle classification remains an open problem.

It is possible to automatically annotate most of the transcripts for Structured teachers
Thus, the focus needs to be on implicit teaching, particularly unsupervised learning to allow the robot to `notice' what the human is trying to teach, or to at least interact with the human to encourage them to act more like a Structured teacher.
Conclusions

• Natural Instruction Methods require sophisticated systems for labeling/learning.
• We can't rely on the expected use of interfaces.
• Some problems for teaching procedures or labeling concepts could be interface-dependent (i.e. implicit labeling).
• The use of new ways of interaction using intuitive interfaces must be explored.
Questions?
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