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Navigation in virtual environment  
Navigování ve virtuálním světě

MASTER THESIS

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Year: 2013

Insert assignment instead of this page before handing in the thesis!!!!

## **Declaration**

I declare, that I have developed my master thesis independently and used only the materials (literature, projects, SW etc.) listed in attached list.

In Prague on .....

.....  
Václav Honzík

## **Acknowledgment**

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# Contents

<b>Introduction</b>	<b>7</b>
<b>1 Background</b>	<b>8</b>
1.1 Related work . . . . .	8
<b>2 GIVE Challenge</b>	<b>10</b>
2.1 Introduction . . . . .	10
2.2 History of GIVE Challenge . . . . .	12
2.3 Task and GIVE world . . . . .	14
<b>3 Dataset</b>	<b>17</b>
3.1 General overview . . . . .	17
3.2 World and Demographic factors . . . . .	23
3.3 Referring expressions . . . . .	24
3.4 Chains of references . . . . .	25
<b>4 Machine Learning on RE</b>	<b>28</b>
4.1 Introduction . . . . .	28
4.2 Timing of the first reference . . . . .	28
4.3 Chains of references . . . . .	30
<b>Conclusion</b>	<b>31</b>
<b>Appendix</b>	<b>34</b>
.1 Histograms for ML . . . . .	35

# Introduction

# Chapter 1

## Background

### 1.1 Related work

Ha et al. (2012) talk about an ‘information gaps’ caused by existence of a non-dialogue communication stream. They concluded that the posture of user, an example of implicit information from the non-dialogue streams, is a significant attribute in modeling of dialog acts. Their goal is to overcome this ‘information gaps’ through machine learning techniques. A shared view of the virtual world in this thesis is also a form of non-dialogue stream, with which must the navigation system work. I also try to apply machine learning to help with language generation.

Viethen et al. (2011a) compare traditional algorithmic approaches with alignment approaches based on psycho-linguistic models for the REG. They use large dataset (16,358 referring expressions) of direction giving task on a shared 2D visual scene introduced by Louwerse et al. (2007). They use three feature sets: traditional REG, alignment and independent (general information about the scene) to build decision tree models (concretely C4.5) combining these feature sets. The alignment based models outperform the traditional REG ones and the best model combines all feature sets to achieve accuracy 58.8% and DICE score 0.81. Not using traditional algorithmic REG features did not result in a significant decrease of accuracy, suggesting that the visual context doesn’t play such an important role as it was believed in the REG research so far. Viethen et al. (2011b) verified this surprising conclusion by varying the visual context. They argue that the relative simplicity of visual scenes used in contemporary research might be the cause of insignificance of the visual context. I would argue that 3D virtual world explored in this thesis is more complex then theirs and therefore this paper can provide some insight into these questions.

Stoia et al. (2006a) were interested in timing of the first reference to the target in 3D virtual world. They predicted whether direction giver refers to the target or delay the reference based on the spatial data. Their attributes were angle and distance to the target, number of visible distractors (either same category as target or all of them) and whether the target is visible. The most important feature in decision tree model was number of visible distractors followed by angle and distance. They



achieved 86% accuracy, compared 70% baseline. The baseline was to refer when the target is visible and to delay the reference when the target isn't visible. Part of the machine learning attempts of this thesis is to replicate first reference timing of Stoia et al. (2006a) on GIVE dataset.

Stoia et al. (2006b) developed decision trees to generate a noun phrase, specified by three slots: determiner/quantifier, pre-modifier/post-modifier and head noun. They used a data-set from 3D virtual world navigation task similar to GIVE dataset. Four categories of features were used: dialog history, spatial and visual features, relation to other objects in the world and object category. The decision trees revealed significant dependencies between the slots and importance of the spatial features. Interestingly, they used three types of system's evaluation. The exact match evaluation produced 31.2% accuracy compared to 20% most-frequent baseline. Comparison with hand-crafted Centering algorithm (Kibble and Power, 2000) ended with similar accuracy, favoring the machine-learning approach for requiring less structural analysis of the input text. Lastly, when human judged the system output, it was at least equal or preferred to original spontaneous language in 62.6% (inter-annotator reliability  $\kappa = 0.51$ ).

Gallo et al. (2008) showed that the Fruit Carts corpus can be used in NLG by case study on message complexity and structural realizations. A logistic regression confirmed that the complexity of verb arguments affects production choice between mono-clausal or bi-clausal structure. In more general terms, the complexity of the virtual environment affects how people speak on all linguistic levels. Referring expression generation should take that into consideration.

Clark and Krych (2004) were examining speakers' monitoring of addressees in a Lego-building experiment. One participant - director - knew 10 Lego models and how to build them. The director was verbally instructing second participant - builder - to build these models. In one group the director could see the builders workspace, in second group he could not and in a third the instructions were audio-taped and simply passed onto the builder. Builders communicated with the directors on the workspace through head gestures and manipulating blocks (placing, exhibiting or poising and so on). When the workspace was blocked of, the task took much longer. In the audio-taped group the builders made many more errors. Directors often altered their utterances midcourse based on builders actions.

# Chapter 2

## GIVE Challenge

Big part of this master thesis revolves around GIVE Challenge. The data I was using to develop the hypothesis where from annotated GIVE experiment. I used GIVE framework to implement and test my hypothesis. Therefore, in this chapter I will describe this academic competition in detail.

First section will answers basic questions such as what is GIVE Challenge, why was it created or what are its interesting properties. In the next section, I will provide a brief history of GIVE Challenge together with some of its results. In the third section, the focus will be a detailed description of the shared task and the virtual world of GIVE Challenge.

### 2.1 Introduction

GIVE Challenge was a series of Natural Language Generation (NLG) competitions run from November 2008 to March 2012. Participants were developing NLG systems to navigate human-controlled avatars in a 3D virtual environment. The real-time navigation was realized through written instructions displayed on the screen. Goal of the navigation was to finish a treasure-hunt game. In figure 2.1 we can see a client software with virtual world and example of an instruction. More detailed description of the task and the environment is in the section 2.3.

Koller et al. (2010a) state that one of the goals of GIVE Challenge was spawning interest in NLG subfield of computational linguistics (CL), inspired by other competitions in this field such as Recognizing Textual Entailment challenge<sup>1</sup> and NIST machine translation competition<sup>2</sup>.

According to Koller et al. (2010a), another important goal was to introduce and explore a new way of evaluating NLG algorithms, techniques and systems in a shared task. More specifically a shared task which was, on one hand, complex enough to encompass multiple NLG subtasks and, on the other hand, was only concerned with

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<sup>1</sup><http://pascallin.ecs.soton.ac.uk/Challenges/>

<sup>2</sup><http://www.itl.nist.gov/iad/mig//tests/mt/>

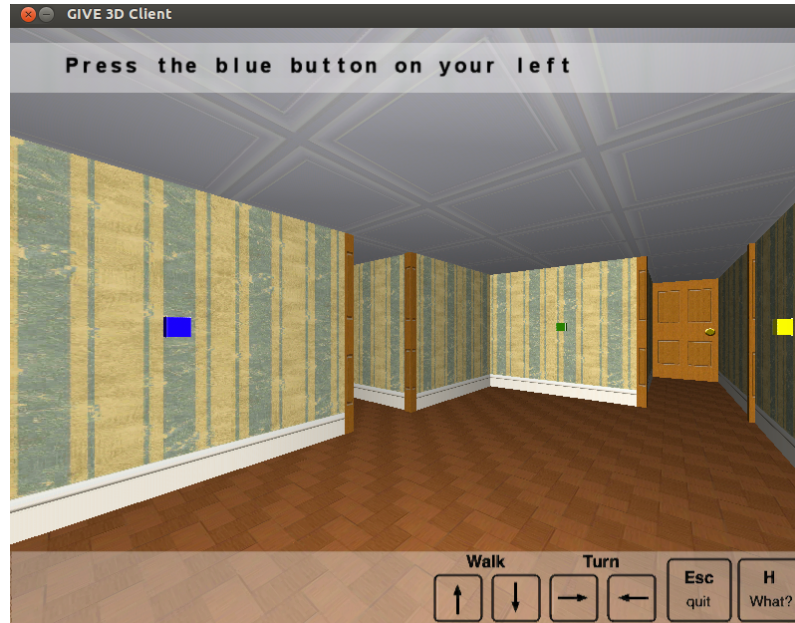


Figure 2.1: A human subject is being navigated through the environment.

NLG and not any other fields of the computational linguistic.

Three basic approaches to evaluation of NLG systems are comparison with annotated corpora, measuring task performance in an experiment and human judges evaluation. Koller et al. (2010a) argue the advantages and disadvantages of these evaluation in more depth, therefore I will only provide a brief summary. The first approach compares output of the NLG system to an annotated corpora, also known as a gold-standard. It is fast and cheap approach, but a problem with it lies in the complexity of the natural language. We can often express concepts in many different ways and there is often no telling which way is a better one. The second approach conducts an experiment and measures task performance on human subjects. Measuring task performance avoids the problems of gold-standard, but it is expensive and time consuming. Lastly, trained human judges are used to evaluate the system. It is less demanding than the second approach, but for the cost of certainty, that the results correspond with results one might achieve with non-expert subjects.

GIVE Challenge proposes and successfully implements a new, in a sense that it wasn't used for NLG before, approach through Internet-based evaluation. The basic premise is using a client-server software methodology. The client is a program installed on test subject computer, which is easily downloadable from a public web-site. The client connects through the Internet to a matchmaker server and random evaluation world is selected. Matchmaker also connects the client to a randomly selected NLG system, which itself, can be hosted on a different server. Client and NLG systems then communicate back and forth until the task is finished. Matchmaker finally logs the entire sessions to database. Figure 2.2 shows that architecture in a simple diagram.

This approach immediately presents several advantages. It does not require physical presence of the test subject in a laboratory. The subject simply downloads the client

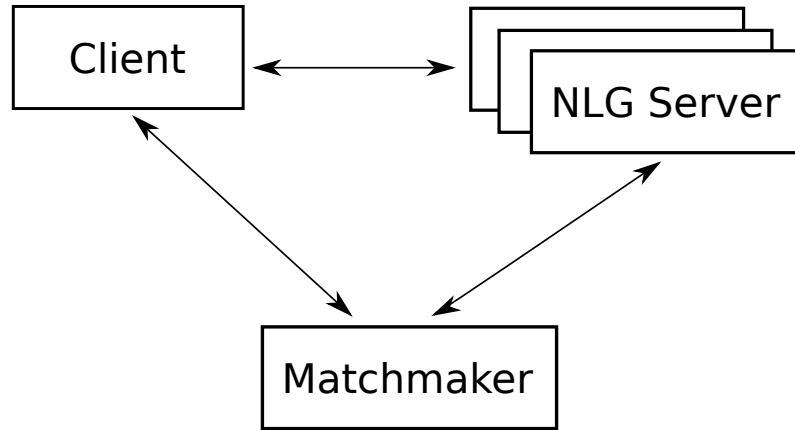


Figure 2.2: Software architecture of GIVE Challenge.

from a website and is able to do the experiment at his/her convenience. Second obvious advantage is a scalability. The number of individuals which can parallelly undertake the experiment is only limited by the servers' load. Thanks to the low costs, advertisement becomes the decisive limitation on the number of subjects. Take for example second instalment of GIVE Challenge which had up to 1800 participants.

On the other hand, part of the control over the experiment is lost in this approach; for example the control over subject pool. Another problem which rises with this approach is that individuals can repeat the experiment.

In addition to Internet-based evaluation, the GIVE Challenge utilizes variety of evaluation measures of both objective and subjective nature. Among objective measure are task success rate, number of instructions or time required to finish the task. For subjective measures a questionnaire was used at the end of the session. The questionnaire mostly used a 5 point scale with question such as how clear where the instruction or how friendly was the system. Some of the measures intentionally collided with each other, putting emphasize on a certain characteristic of the system.

Having presented the basic concept of GIVE Challenge and reasons for its creation, I will now move onto brief history of this competition.

## 2.2 History of GIVE Challenge

The first instalment of GIVE Challenge (GIVE-1) was publicized in March 2008. Koller et al. (2010a) report on this instalment and are the source of following information. For more details please refer to their paper. The data collection period was from November 2008 to February 2009. Four teams participated in this challenge, namely from these universities: University of Texas at Austin, Universidad Complutense de Madrid, University of Twente and Union College. The team from University of Twente submitted two systems, making the final number of systems five.

What is important to note about GIVE-1 is a different world representation from the

following instalments. GIVE-1 used discrete square grid for player movement. Player was able to rotate only by  $90^\circ$  and walk forward and backwards by one square of the grid. That had a major impact on the design of NLG systems. Participating teams at least occasionally used this grid in their references (eg. *move forward three steps*). Afterwards organizers realized that the grid and the discrete movement made the task easier than intended and they were after GIVE-1 removed.

Altogether, 1143 valid games were recorded. The demographics featured a majority of males (over 80%) and wide spread over different countries in the world. For the actual results, the system from Austin significantly outperformed all other systems in task completion time. At the same time systems from Union and Madrid outperformed other systems in success rate. That shows the significance of different measures for the evaluation. Similar interesting conclusion in both objective and subjective measures can be found in previously mentioned paper. Apart from objective and subjective measures, the report examined influence of English language proficiency and differences between evaluation worlds. The English proficiency had an impact on the task success rate but solely for the least proficient category. The evaluation world also had a significant influence on the task success rate.

Finally, the first instalment also compared the Internet-based evaluation with more standard laboratory evaluation. The conclusion was that Internet-based evaluation provides meaningful results comparable and even more precise in some areas to the laboratory setting.

The second instalment (GIVE-2) run from August 2009 (data collection starting in February 2010) to May 2010 and is thoroughly described by Koller et al. (2010b). Following information are based on this paper. Biggest difference to the GIVE-1, which was mentioned previously, is that players were now able to move freely. This made the instruction generation considerably harder. Additionally, the questionnaire was revised and a few new objectives measures were introduced. Evaluation worlds used in GIVE-2 were considerably harder than in GIVE-1. Number of distracting buttons was increased and same-colored buttons were in some cases next to each other. Also number of alarm tiles was increased. Otherwise, the architecture and the rest of the details stayed the same as in GIVE-1.

This time 1825 games were played over seven NLG systems developed by six teams from: Dublin Institute of Technology, Trinity College Dublin, Universidad Complutense de Madrid, University of Heidelberg, Saarland University and INRIA Grand-Est in Nancy (2 systems).

There was a big drop in success rate, most likely linked to the free movement and the increase of difficulty in the evaluation worlds. Similarly to results in GIVE-1, there was an influence of English proficiency and game world on the task success rate. Additionally, age of the subject played a role in the time required to finish the task and number of actions to finish the task (younger subjects being faster and requiring less actions). The difference between genders in time required to finish the task disappeared in GIVE-2.

Following GIVE-2 was so called Second Second instalment (GIVE-2.5), which kept almost the same settings as GIVE-2. There was just a small addition to objective

measures and a reduce in the number of subjective questions. The data collection took place between July 2011 and Mar 2012. Striegnitz et al. (2011) reports on the partial results of 536 valid games from July and August 2011, which however constitute a majority of the final number of 650 valid games.

Eight NLG systems participated from 7 teams: University of Aberdeen, University of Bremen, Universidad Nacional de Córdoba, Universidad Nacional de Córdoba and LORIA/CNRS, LORIA/CNRS, University of Potsdam (2 systems) and University of Twente. In this instalment the teams employed more broad spectrum of approaches. Team from University of Bremen used decision trees learned from GIVE-2 corpus. Universidad Nacional de Córdoba and LORIA/CNRS, LORIA/CNRS selected instructions from a corpus of human to human interactions. The teams also often included algorithms from existing NLG and CL literature.

Apart from comparing the systems through objective and subjective measures, Striegnitz et al. (2011) again examined effects of evaluation worlds and demographics factors on task success rate. The evaluation worlds and the English proficiency had an effect. Additionally computer expertise and familiarity with computer games significantly influenced the task performance. The difference between male and female subject wasn't significant.

Following section describes the shared task in more detail and lists possible contents of GIVE virtual worlds.

## 2.3 Task and GIVE world

GIVE world is a 3D virtual world. The world is indoor in a sense, that it comprises rooms connected by doors. It's defined in a human-readable format and stored in text file. Following objects can be places in a world:

- Alarm tile
- Button
- Door
- Landmark
  - Bed
  - Chair
  - Couch
  - Dresser
  - Flower
  - Lamp
  - Table
  - Window

- Picture
- Safe
- Trophy
- Wall

In addition, some of these objects can have attributes, states or can operate other objects. Buttons have colors as an example of attribute. Doors and safes can be in a closed or an open state. Buttons can operate doors, safes or pictures.

Walls are actually created automatically by defining shapes of rooms. Rooms can have rectangular shape or can be defined by a polygon. I will sometimes use a term “corridor” which is a connecting room, usually not containing any button.

The landmarks serve as a decoration but they can be used in an expression generation. Picture is technically a landmark as well, but in GIVE Challenge it often serves another purpose. It covers the safe and needs to be put aside by a button press.

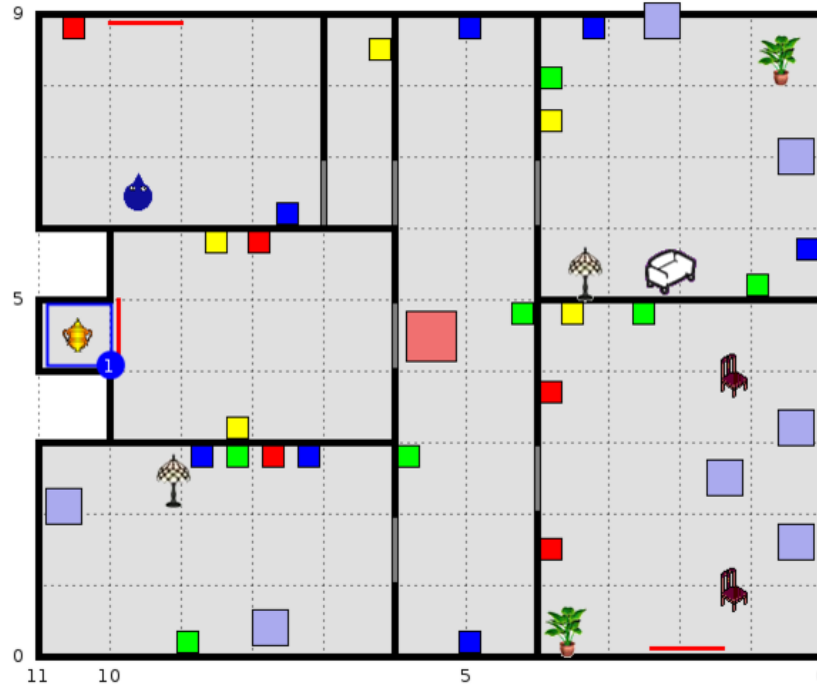


Figure 2.3: Example GIVE world viewed in GIVE map viewer utility.

Figure 2.3 shows an evaluation world number one from GIVE-2.5. In top-left room we can see player starting position. Buttons are colored squares on the walls. Grey bars on the walls are closed doors. Trophy in a safe is in the middle-left room. There are also landmarks (like lamp or chair) and one big red square marking an alarm tile.

The flexibility of GIVE world creation allows relatively broad range of scenarios for the task. On the other hand, all the GIVE Challenge instalments consisted of similar sequence of steps.

The goal of all the GIVE Challenge worlds is to pick up a trophy. The trophy is hidden in a closed safe. In order to open the safe a sequence of buttons, usually counting somewhere around 6 buttons, has to be pressed. The safe can be also hidden by a picture, which needs to be put aside. The buttons in a safe-opening series are often in different rooms. Rooms can be also closed off, requiring another button press to open the door. While moving around the world, player has to avoid alarm tiles. Stepping on an activated alarm tile causes an immediate loss. Alarm tiles can also block the path and need to be deactivated by a button press. Some buttons also cause an alarm and an immediate loss.

Depending on the number of rooms, complexity of buttons arrangement and length of safe-opening sequence, the task can range from short and trivial problem easily handled by a few instruction templates, to a long and hard case, where it's impossible to capture every possible scenario.

To summarize, navigation system of a player in the GIVE world has to deal with following steps. Note that their order depends on the world definition and they can be thought of as layers of behaviours the system must enforce on player.

- Avoid alarm tiles
- Avoid pressing alarm-causing buttons
- Deactivate path-blocking alarm tiles by a button press
- Open closed-off rooms by pressing correct buttons
- Press a sequence of buttons to open the safe
- Reveal safe behind a picture by pressing correct button
- Take the trophy

After the safe was opened and possibly revealed from behind the picture player can pick up the trophy and therefore win the game.



# Chapter 3

## Dataset

In chapter 2 it was mentioned, that some teams participating in GIVE Challenge tried to use a corpora of a human to human interactions in GIVE scenario. They were learning language expression or decision-making process and applying them in their NLG systems. The teams were however relying on small self-collected datasets. In a light of this, organizers of GIVE Challenge decided they would collect and provide dataset for future use. This chapter serves as an introduction and analysis of this dataset.

As a side note, Striegnitz et al. (2012) report on a smaller German dataset, which is similar to the one I will be talking about.

In the first section, I will introduce the dataset and provide technical details of how it was created. Second section, will, after the fashion of GIVE Challenge look how world and demographic factors influenced the task performance. Next section analyses REs in the dataset. Last section explores a phenomenon of chains of references.

### 3.1 General overview

The data-collection started in July and finished November of 2012. Through that period 21 interactions between two human subjects were recorded. Originally, 22 pairs participated, but one of the pair failed to finish the tasks and is excluded from the dataset. The subjects were asked to bring someone they know and they were financially compensated for the effort.

The set-up for the experiment is in the figure 3.1. One human subject was an instruction giver (IG). He is on the right in the figure 3.1. His role was essentially the role of NLG system in GIVE Challenge. He/she was able to see a map of the world, which was updated in real-time and he/she got information about all necessary steps to finish the task. In addition, he was able to see the other's person client screen. He communicated with the other person through a microphone and his goal was to navigate the other person through the world and make him finish the treasure-hunt.

The other person was an instruction follower (IF). He/she is on the left in the figure

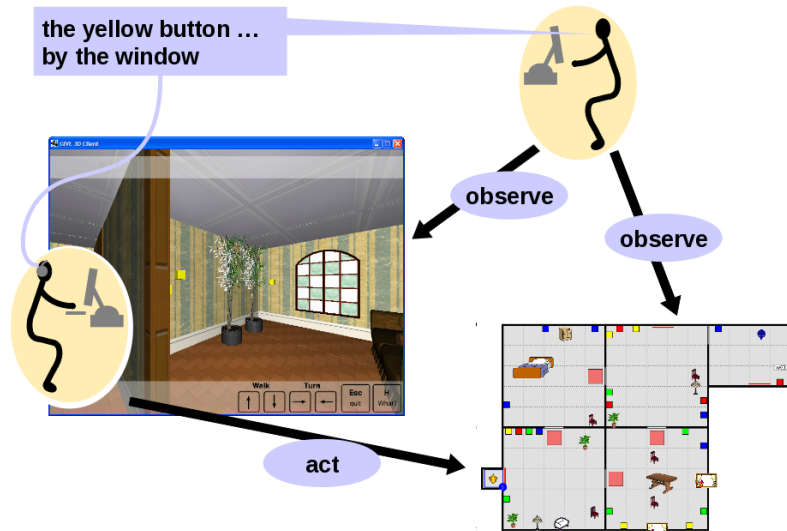


Figure 3.1: Experiment set-up of data collection

3.1. He/she interacted with the client and moved the avatar around the world and was able to press buttons. IF listened to IG's instructions through a headset.

Each pair did one short tutorial world. After that they switched roles of instruction giver and instruction follower. Following was one “normal” world randomly chosen from two variants, marked world 1 and world 3 in the dataset. Maps of the worlds 1 and 3 are in the figures 3.2 and 3.3 respectively. Finally they did a difficult version of the other variant (if they started with world 1 the difficult version was for world 3 and vice versa). The difficult versions are marked 1-d and 3-d in the dataset. A difficult version of the world had an increased number of distracting buttons and landmarks compared to the “normal” version, as can be seen in the map of world 1-d in figure 3.4. If not present in the report or not stated otherwise, the short tutorial worlds are normally excluded from the analysis.

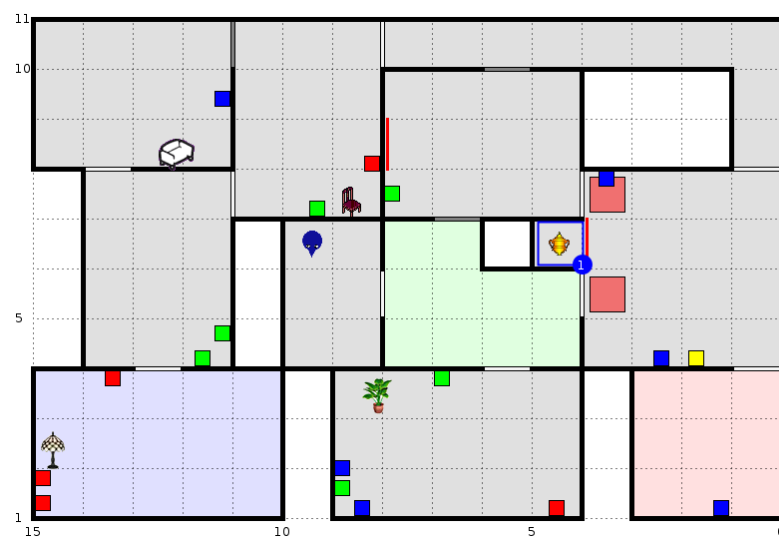


Figure 3.2: Map of the world 1 - normal version.

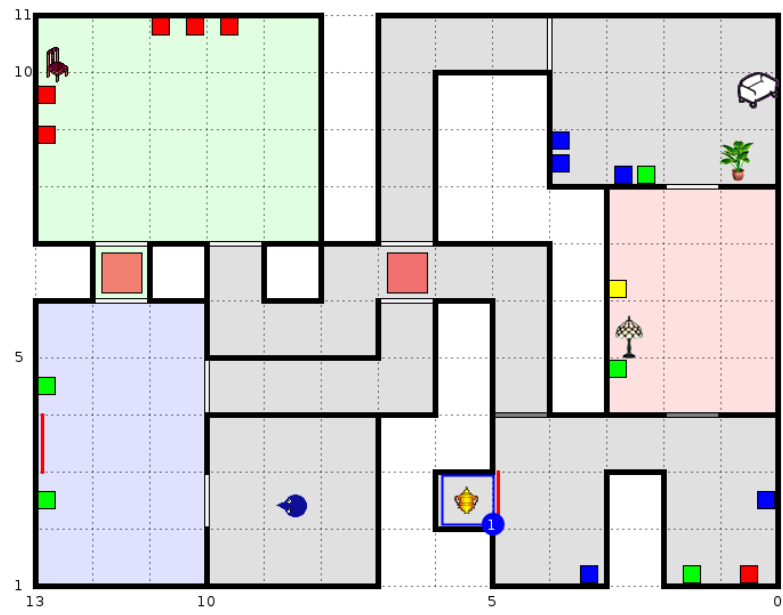


Figure 3.3: Map of the world 3 - normal version.

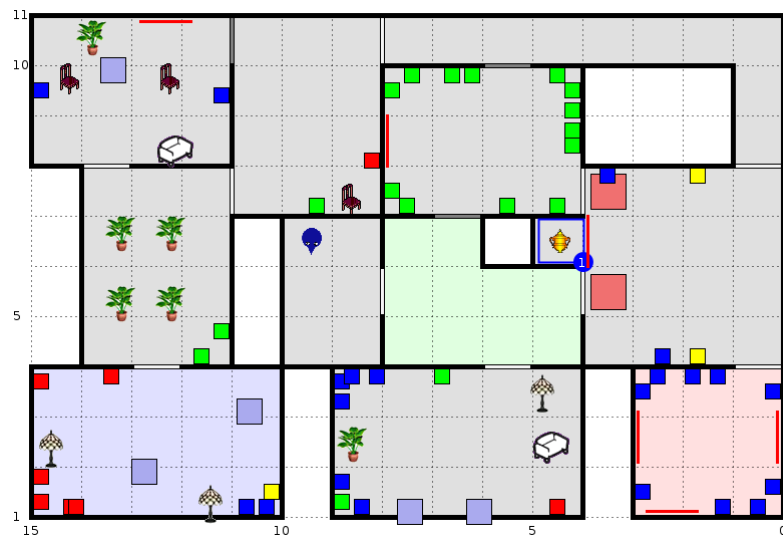


Figure 3.4: Map of the world 1 - difficult version.

1. Overall, my partner gave me good instructions.
2. Interacting with my partner wasn't annoying at all.
3. My partner's instructions were clearly worded.
4. When I had problems with the instructions, we solved them quickly.
5. I enjoyed solving the task.
6. I felt I could trust my partner's instructions.
7. I really wanted to find that trophy.
8. My partner immediately offered help when I was in trouble.
9. I would recommend this experiment to a friend.
10. My partner's instructions were not repetitive.

Similarly to the GIVE Challenge, after all 3 rounds subjects were asked to fill a questionnaire. Its purpose was to get demographic and other relevant information on subjects. The questionnaire can be divided into three parts. First part was only filled out by IF and rated IG and his instruction giving on a scale from 1 to 7. Complete list of its questions follows:

Second part was filled by both IF and IG and was concerned with their navigation skills. To measure the ability to navigate in the world the Santa Barbara Sense of Direction (SBSOD) scores were used Hegarty et al. (2002). Again the questions were on a scale from 1 to 7. Note that some of the question in the following list are of positive nature (higher rating equals better navigation skill) while other are of negative nature, therefore these scores had to be normalized.

Finally, the last part of the questionnaire was of a demographic character. We can see questions about age, gender, language and computer expertise, 3D games experience and knowledge of the partner in following list.

Many of these questions are explored in the next section as a potential factors influencing the task performance.

As was mentioned in chapter 2, the entire session is logged to the database. The player's position, orientation and all visible objects are logged at fixed rate. Moreover, other information as buttons presses or an end of the session are also stored in the logs. Because the worlds are static, distances and angles between player and other game's objects are easily computed from these logs.

Apart from logs, there are of course sound files of IG giving directions. These were transcribed and together with some information from the logs transformed into ELAN files. ELAN is an annotation software (Sloetjes and Wittenburg, 2008). I will use the term automatic annotations for the ELAN files created from logs and transcribed audio.

1. I am very good at giving directions.
2. I have a poor memory for where I left things.
3. I am very good at judging distances.
4. My "sense of direction" is very good. I tend to think of my environment in terms of cardinal directions (N, S, E, W).
5. I very easily get lost in a new city.
6. I enjoy reading maps.
7. I have trouble understanding directions.
8. I am very good at reading maps.
9. I don't remember routes very well while riding as a passenger in a car.
10. I don't enjoy giving directions.
11. It's not important to me to know where I am.
12. I usually let someone else do the navigational planning for long trips.
13. I can usually remember a new route after I have travelled it only once.
14. I don't have a very good "mental map" of my environment.

1. What is your age?
2. Are you male or female?
3. What is your profession / major / favorite subject in school?
4. How would you rate your computer expertise?
5. How familiar are you with 3D computer games?
6. How many hours per week do you play 3D computer games?
7. Was there a time in your life when you played more 3D computer games? If so, how many hours did you play then?
8. What languages do you speak? Please indicate how well you speak each on a scale from 1-5, where 5 is your native language.
9. Did you already know the second participant?
10. How well do you know the second participant?
11. Have you worked collaboratively with the second participant before? (For example, when doing homework or preparing a class presentation?)
12. Have you played 3D computer games with the second participant before?

Building on top of these automatic annotations are manual annotations. They are primarily concerned with referring expressions and also stored in ELAN format. Most referring expressions in GIVE aim to locate a button, which needs to be pressed. I will call the button, which is a goal of an referring expression, the target button. Which button is the target button of a reference is one of the layers in the manual annotations. Another layer of the annotations is some basic grouping of the references. Whether it is a reference to a single button, to a group of button, to a landmark and so on. Third layer looks deeper into the contents of the reference. It notes whether the reference contains for example the color of a button, whether distractors or landmarks are part of the reference or whether the reference explicitly points out that the button was already pressed before.

Previously mentioned logs, automatic annotations and manual annotations together form the dataset this chapter is dealing with.

An example of what can be extracted from the data is in the following text. Spatial information are transcribed in parentheses for the sake of clearness.

(IF enters a room)  
 IG: Go towards the red buttons.  
 (IF turns right and start walking, but he turns too much)  
 IG: No the ones next to the lamp...  
 (IF corrects his direction)

IG: Yeah that lamp. On the right.  
(IF is facing three buttons.)  
IG: Press the button on the wall you are looking at, that's far from the lamp and on the left.  
(IF goes towards the correct button and stops close to him)  
IG: Press it.

## 3.2 World and Demographic factors

As was noted repeatedly in the chapter 2, the world had significant influence on the task success rate in GIVE Challenge. However the dataset was created in a different manner, so the question about influence of worlds must be reformulated. First of all, all the sessions were successful except for a one which was discarded. Therefore, the task success rate no longer makes sense. Instead, I will measure task performance by time required to finish the task (duration) and also use other performance measure when appropriate. Secondly, the normal worlds were designed to have the same or similar difficulty in order to minimize effects outside of navigation strategy. Same idea goes with the difficult worlds.

Despite the design choices, I found out that the normal worlds 1 and 3, had a different mean duration (p-value 0.0473 for two-sample t-test). There are multiple explanation for this difference. Relatively small number of subjects is certainly one of them. We can also notice in the figure 3.3 slightly complicated system of hallways in the center of world-3. But this discovery does not have major influence on my work. Moreover, the difficult world did not have significant difference between their mean duration (p-value 0.6195 for two-sample t-test).

Another thing I was interested in was influence of gaming experience of both participants on certain performance measures, namely on the duration, on the average speed of IF movement and the time IF spent moving. The average speed of IF is simply a total distance the avatar controller by IF travelled in a session divided by duration. The time IF spent moving aggregates time where avatar was either motionless or only rotating in place.

I found correlations between gaming experiences and these variables. Not surprisingly, these correlation are especially high for IF, since he/she is the one who is actually playing the world. The past gaming experience (questions 7 in third part of the questionnaire) are more important than contemporary playing (question 6 in the third part of the questionnaire). Most prominent are the hours per week spent playing of IF at the past peak gaming period (question 7), the same variable for IG and hours spent gaming per week for IF at present (question 6). For the difficult worlds some correlations change slightly. In general, individuals who are familiar with games (gamers) take less time to finish the world, they spent more time moving and they have higher speed.

The influence of SBSOD scores (second part of the questionnaire) on the task proficiency was another thing I have looked at. Correlation matrix revealed weak or

almost no correlation between SBSOD scores and time needed to complete the world.

The data suggest that there is positive correlation between male gender and task proficiency measured in the duration. The effect of male IG diminishes in the difficult worlds but the effect of IF is even stronger in the difficult worlds. However there are several facts to take in consideration here. First of all, we don't have enough data to have a statistically significant conclusion. This correlation might have also been caused by having more male gamers than female gamers. Lastly, there has been research about influence of gender on spatial cognition and mental rotation; an example of more recent one is (Geary et al., 2000). They conclude that males are more proficient in tasks requiring mental rotation. Since IG have to do mental rotation while giving direction in GIVE scenario, this might be a source of correlation. Another paper worth considering on this topic is (Moffat et al., 1998), which found a gender difference in time required to finish a virtual maze.

The age of IF have positive correlation with task proficiency measured in the duration and in difficult worlds this correlation is one the strongest ones: 0.6. Older IF are also moving less and are generally slower. For IG the correlations have the same direction, however they are much weaker.

Lastly I was interested how familiarity of participants with each other (questions 9-12 in the third part) influenced the task performance. The knowledge of the partner had an impact on the task efficiency. What was interesting is that, previous cooperation with the partner became much more important for the difficult worlds, while not having much impact in normal worlds. One interpretation is, of course, faster learning for pairs familiar with each others. Other one might be that in the normal worlds the referring expressions are relatively simple and does not leave much space for errors. On the other hand in the difficult worlds familiarity reduce chances of misinterpretation of complex expressions.

### 3.3 Referring expressions

Because REs are the main focus of my research, this section serves as an introductory analysis of REs in my dataset.

Overall, 793 REs were annotated in the manual annotations. Apart from time interval of the reference, several other facts were annotated in the manual annotations. First of all, the target button of each RE was annotated. The count of distinct target buttons is 29.

REs were also separated into 5 high-level categories depending on what they refer to. The overview of the categories is in the following list:

- Target - Referring to the target button
- Group - Referring to a group of buttons, one of which is the target button
- Landmark object - Referring to a landmark (any object or room feature, but not a button) which will then be used to locate the target button



- Landmark button - Referring to a distractor button as a landmark
- Remove button - Referring to a distractor button to exclude it

Percentage count of the categories is in the table 3.1. References to target button are a dominant category. Around 10% of references are group references. References to landmarks occupy only 6% of all references.

Category	Percentage (%)
Target	82.47
Group	10.34
Landmark object	5.04
Landmark button	1.39
Remove button	0.76

Table 3.1: Percentage of REs in the groups

### 3.4 Chains of references

Interesting phenomenon I have noticed and further explored in the dataset are consecutive references to one button. It can be seen in following sentences: “Straight ahead of you there on the opposite wall there are two blue buttons. Press the one on the right. The one close to the picture.” The IG started of with a references to a group of two buttons; the target button being one of those two. In the second sentence he picked out the target button from the group. In the last sentence IG made another reference containing landmark, adding redundant information. Since the references are concerned with one target button and follow each other relatively fast, I have called them chains of references (chains, in short).

The chains vary in length, from short ones, consisting of only two references, up to lengthy ones with eight references following each other. The example from previous paragraph is three references long. Figure 3.5 shows histogram of the chains length.

The chains are significant part of the discourse, in fact over 77% of all RE belong to a chain. However, the chains have multiple linguistic functions, which makes them difficult to explore. Even inside one chain, there are often combination of functions. I have manually annotated some common functions of the chains. Most common one is to inform IF that he is supposed to press the target button. A simple example of this function, which I call action, is in following discourse: “The red button in front of you. Press that one.” It may sound redundant to use action function as the experiment progresses, since the IF are not manipulating the buttons in any other way than pressing them. But I have found out that it’s often the case.

Another common function is confirmation: “That same red button we pressed before, we’ll press that again. Yeah that one.” The IG confirms at the end of previous utterance that IF is looking at or heading to a correct target button.

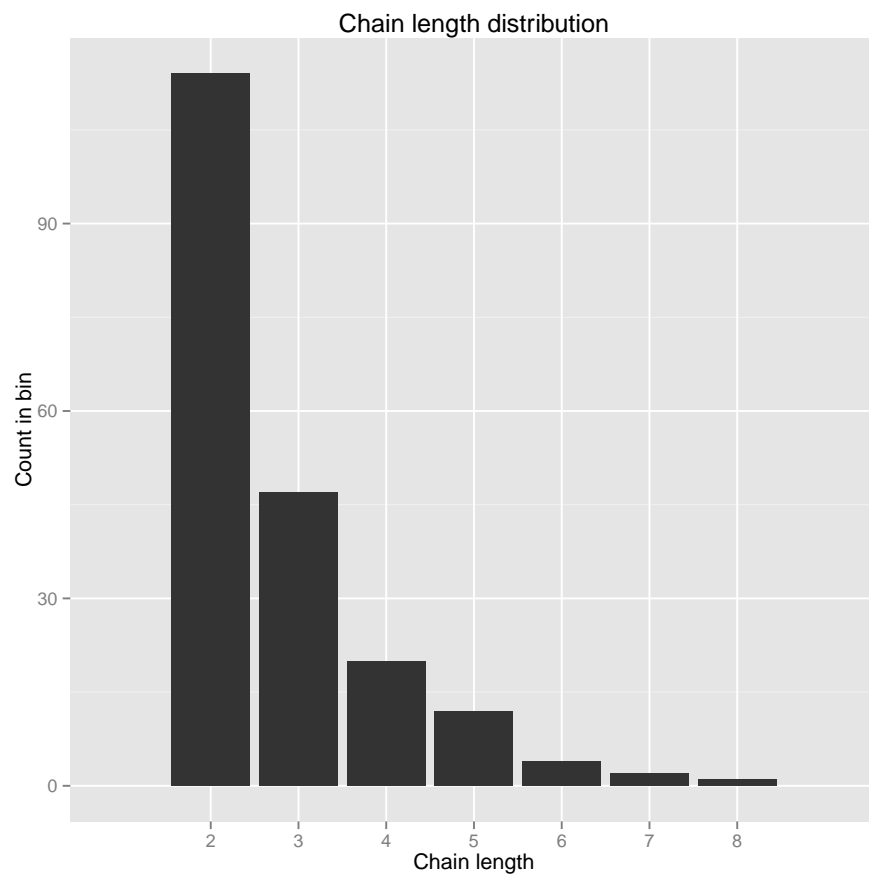


Figure 3.5: Histogram of the chain length

IG often utter a RE, which does not perfectly “picks out” the target button from the set of buttons in the room. IG can make up for that information deficit with confirmation function or further specify with another RE. That is a specification function, as in following two sentences: “Now that green button. You want the one closer to the lamp.”

When a group of buttons is utilized in RE and the target button is part of that group, it is inevitable that IG will have to make another RE to “pick out” the target button from the group. Therefore group references imply chains of references and should be considered as one of the functions. Simple example of the group function: “Two blue buttons on the wall. Hit the blue button on the right side.”

When IF has clearly chosen the wrong button, IG will try to correct that error. I call that an error function. Following extract features this function: “That blue button. No no no. The other. That one.”

Summary of the functions is in the table 3.2. Please note that these functions are not exclusive. One chain can have both confirmation and specification function.

Function	Chains containing it (%)
Action	66.16
Confirmation	29.29
Specification	25.25
Group	24.74
Error	11.11

Table 3.2: Percentage of chains having specific functions

# Chapter 4

## Machine Learning on RE

RE are big part of language realization of a navigation system and especially so in the GIVE scenario. Major part of my work was attempt to apply machine learning techniques on GIVE dataset with a clear goal to help navigation system with RE. This part is presented in this chapter.

In the first section I'll describe attempts at predicting timing of the first reference to a target button. Second section talks about modeling of chains of references.

### 4.1 Introduction

### 4.2 Timing of the first reference

Work of Stoia et al. (2006a) was previously mentioned in related work section of chapter 1. They applied machine learning on timing of the first reference in a 3D virtual world. The set-up of their experiment is quite similar to the GIVE's one and so I decided it would be interesting to replicate their methodology on GIVE dataset.

First of all, there are two important differences between their experiment and GIVE dataset to keep in mind. Their tasks also included different actions than pushing buttons (e.g. picking up items) and their worlds had higher diversity and smaller frequency of the distractors.

Now for the preprocessing. I extracted the first references to buttons which needed to be pressed from dataset. I excluded plural references, because of their complexity. Some buttons were placed on top of each other and IG wasn't sure which one need to be pressed. These were excluded as well because of the unnecessary confusion. That left me with 351 first references. Same as Stoia et al. (2006a) I averaged spatial information over 0.6 seconds window centered on the time of the reference. For each first reference I have chosen one negative example, where IG could refer to the target but chose not to. I picked negative examples randomly from interval between entering room and time of the first reference. Overall, that is 702 data-points with perfectly balanced classes.

As for attributes, I have chosen similarly to Stoia et al. (2006a) various spatial information. Following list of attributes also includes appropriate figures' numbers. These figures are histograms of the attributes for positive and negative cases and can be found in Appendix.

- Distance to target button - figure 2
- Absolute value of angle to target - figure 3
- Whether target is visible (True/False) - figure 4
- Number of distractors - figure 5
- Number of distracting buttons - figure 6
- Number of visible buttons with smaller angle to IF than the target button - figure 7

Once I have extracted these features I have used three machine learning techniques: C4.5 decision tree because of their easy interpretation, naive Bayes to observe effect of all attributes and Support vector machine for linear classification. I used Weka software implementation of previous algorithms (Hall et al., 2009).

For all the algorithms I used a standard ten-fold cross validation. The results can be seen in table 4.1. Pruned decision tree for timing of the first reference can be seen in figure 4.1. I used two simple baselines to compare the results with. I have perfectly balanced classes so the first baseline is 50%. Simple rule for the first reference is to refer when the target is visible, and delay it if the target is not visible. In my case that is 64.2%.

Model	Accuracy (%)
Class baseline	50.00
Visibility baseline	64.2
Naive Bayes	<b>64.70</b>
C4.5	63.31
SVM	55.42

Table 4.1: Results of first reference timing modeling

Only one algorithm was able to get over visibility baseline and not by a significant amount. These results were surprising, because Stoia et al. (2006a) had success with the same approach on a similar dataset. Reasons for this difference are probably in the differences between their and GIVE set-up as mentioned at the beginning of this section. With increasing number of distractors and particularly distractors of the same category, it seems that spatial features loose their power in predicting the timing of the first reference. The number of visible distractors was the best attribute in their decision tree, but in my tree (figure 4.1) it had lower information gain and moreover the tree did the split on number of visible buttons not of all distractors.

After not having success with timing of the first references I have focused on chains of references.

```
Distance to target <= 4.45
| Is target visible? = False: DELAY
| Is target visible? = True
| | Distance to target <= 2.51: REFER
| | Distance to target > 2.51
| | | Number of distracting buttons <= 4.67: REFER
| | | Number of distracting buttons > 4.67: DELAY
Distance to target > 4.45: DELAY
```

Figure 4.1: Decision tree for first reference timing

## 4.3 Chains of references

# Conclusion

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# Appendix

## .1 Histograms for ML

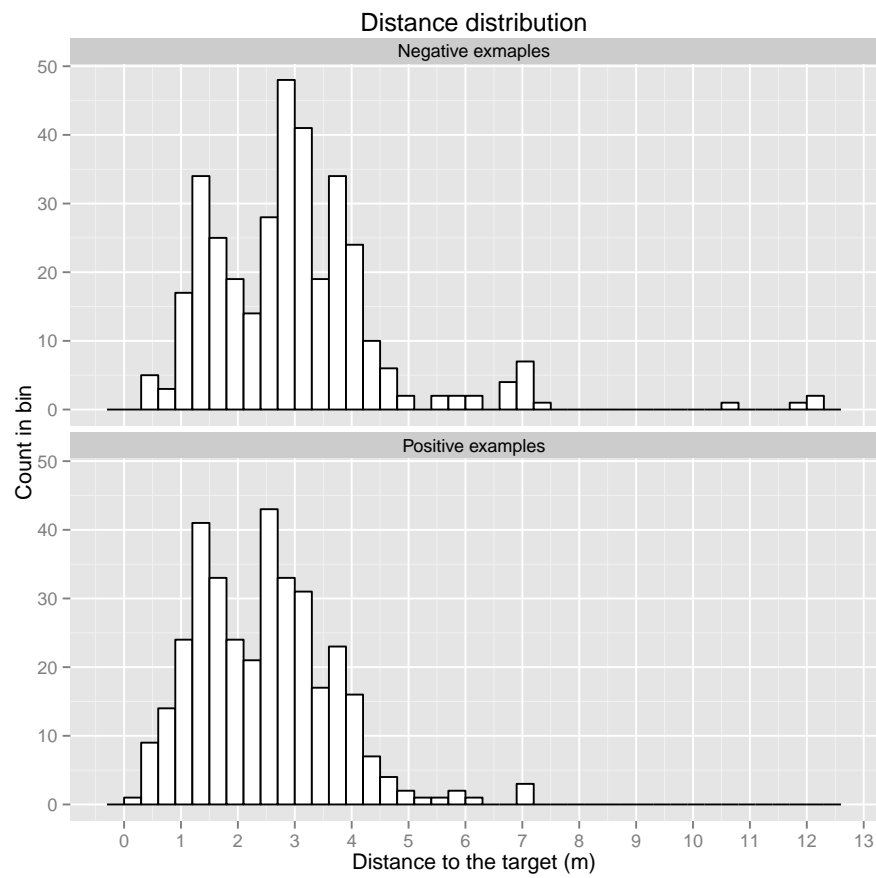


Figure 2: Histogram of attribute distance to the target

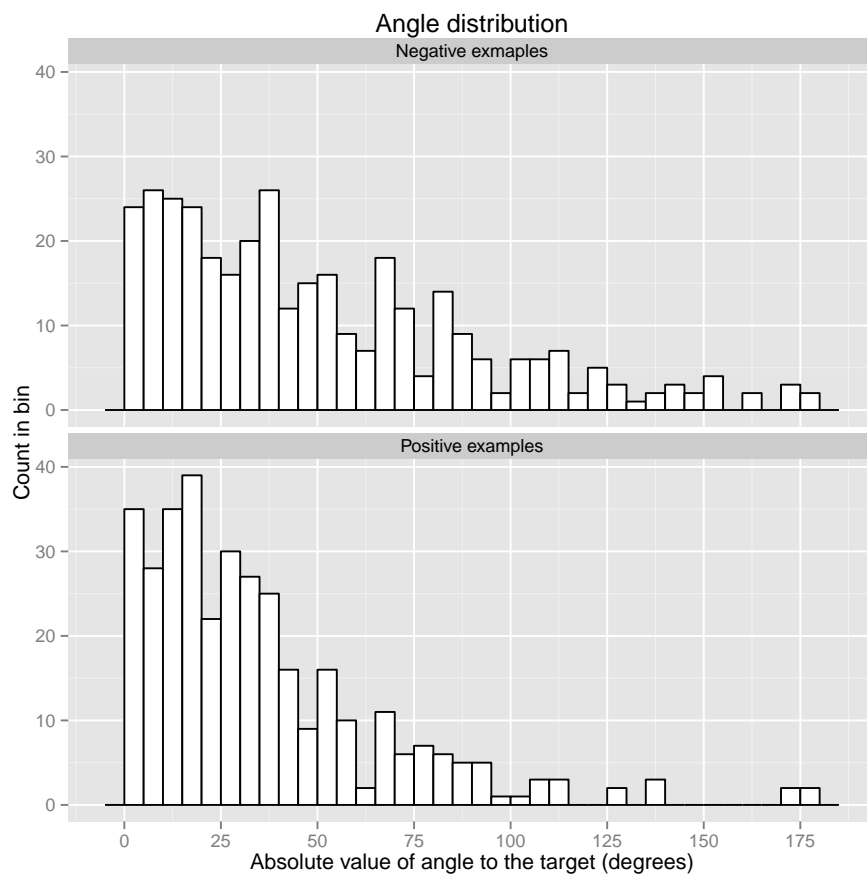


Figure 3: Histogram of attribute angle to the target

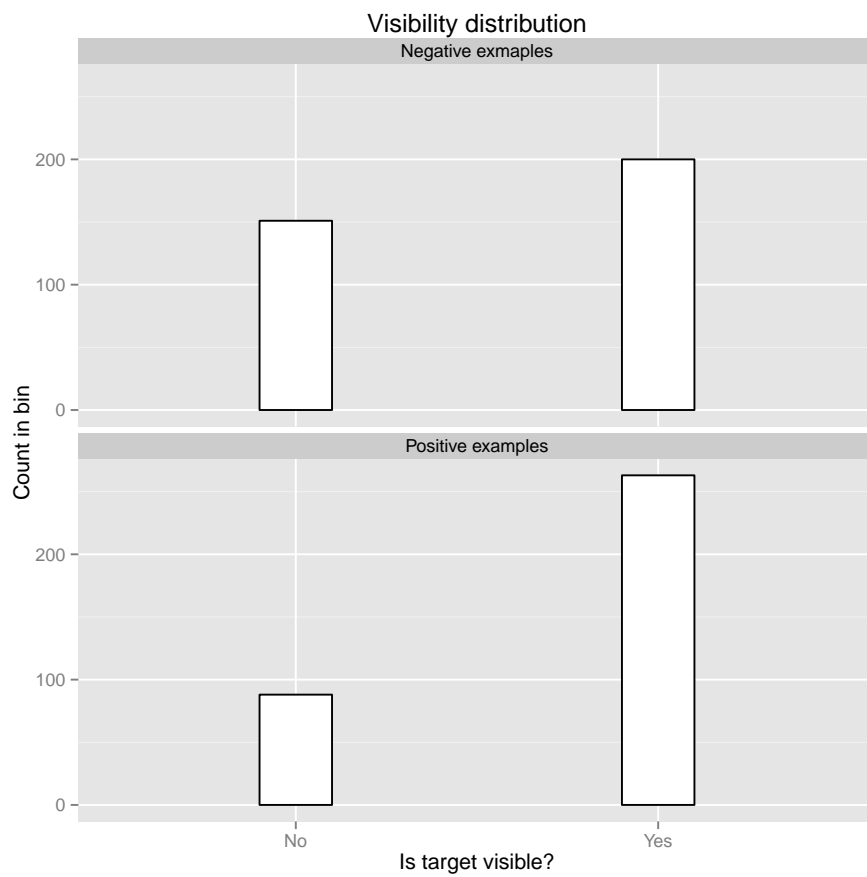


Figure 4: Histogram of attribute whether the target is visible

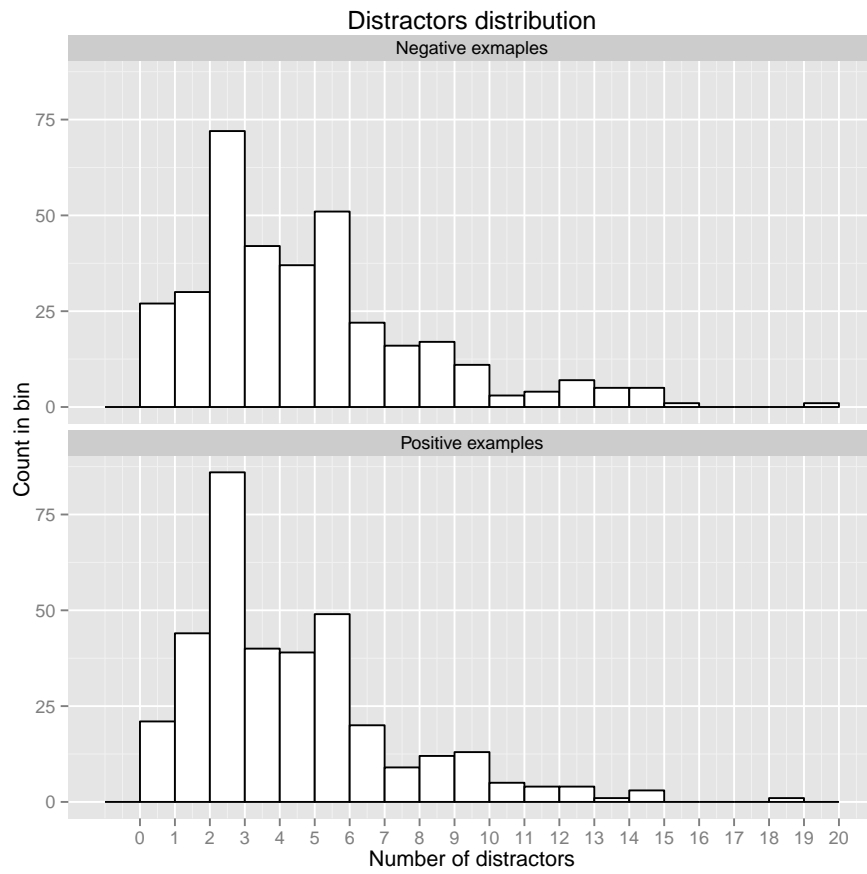


Figure 5: Histogram of attribute number of distractors

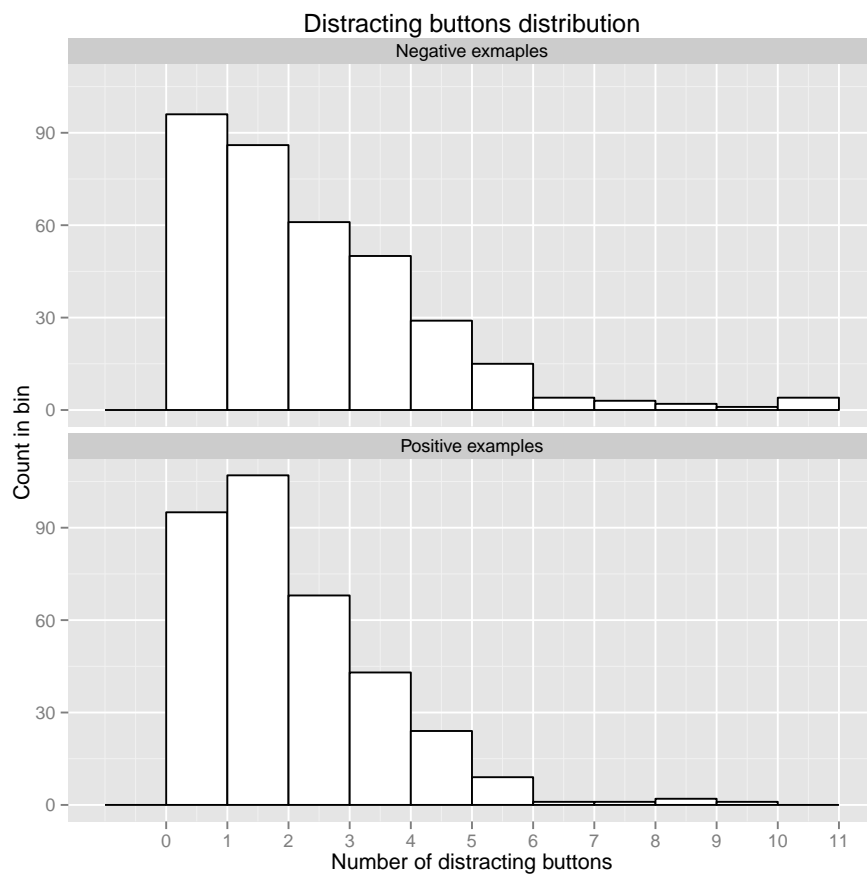


Figure 6: Histogram of attribute number of distracting buttons

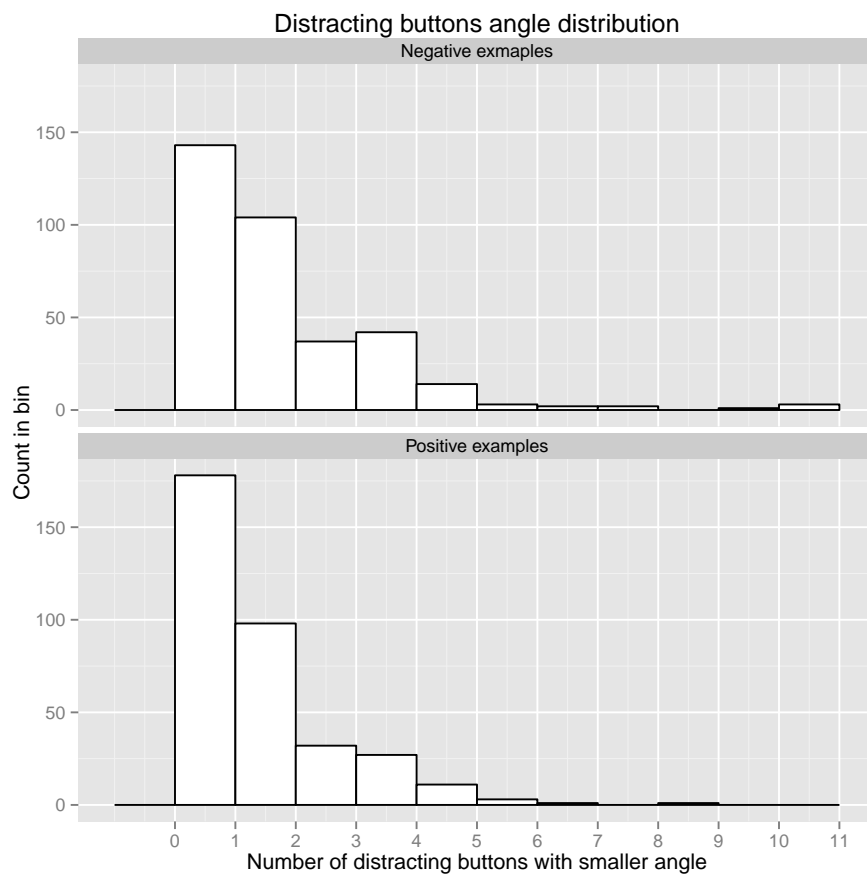


Figure 7: Histogram of attribute number of distracting buttons with lesser angle