Behavioral clues for forager transitions in a fully tracked honeybee colony

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Bachelor of Computer Science

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I would like to dedicate this thesis to my loving parents …

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

Janek Szynal
April 2019

Acknowledgements

And I would like to acknowledge ...

Abstract

This is where you write your abstract ...

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Chapter 1

Introduction - 95%

1.1 The honeybee and the division of labor

A honeybee (*Apis mellifera*) colony manifests multiple fascinating examples of complex adaptive behaviour. Localized cues exchanged between individuals amount to emergent directional signals for the entire colony in ways heavily investigated, but often still not completely understood.

One of the most notable and well-researched adaptive mechanisms of a colony is its division of labor (DOL). During the winter (a season of low activity for the bees), the colony focuses on survival and its workers are generalists, performing sets of tasks not easily distinguishable from those of other workers.

For the spring-summer season, however, the hive's goals change and along with them, the patterns of labor division. Hive growth and resource accumulation take priority, and specialization eventuates amongst workers. They begin to fill distinct roles, the allocation of which highly correlates with age (an effect known as temporal polyethism) - but is also grounded in the colony's current needs and in environmental factors affecting it (adaptive behaviour) [4]. Groups of workers that can be categorized as performing the same set of tasks are commonly referred to as castes. It is common to recognize four of them in the temporal caste system that the worker bees exhibit in the summer: *cell cleaners, nurses, middle-aged bees (MABs),* and *foragers*. This work concentrates on the transition between *MABs* and *foragers*, possibly the most distinguishable and important in the lifecycle of a bee.

1.2 The foraging phase

The foraging phase is the last one in a bee's life and comes with an increased risk of death. It is often proposed that this has to do with the extreme strain foraging puts on their bodies - essentially causing them to work themselves to death. This is supported for example by [8], who have shown honeybee flight to cause extremely high metabolic rates and induce oxidative stress, likely significantly accelerating the ageing process and causing early deaths. On the other hand, the results of [5] suggest that foragers' deaths are usually caused not by senescence, but rather by the heightened risks of outside life that come with their function (such as the risk of predation). According to their findings, forager mortality rates are constant with respect to age - and not accelerating, as would have been suggested by the body strain hypothesis.

Regardless of the reasons behind it, foraging nearly always ends in the death of a bee. That fact, combined with an estimate of the length of the foraging phase (mean of 7.7 days ± 0.75 days, median of 7 days, and range of 2 to 17 day according to [5], should allow us to get a very simple estimate of the foraging period, which we can then use to validate the results we produce with more involved methods.

1.3 The *BeesBook* project

This work operates on data from the 2016 iteration of the BeesBook project [7]. A hard- and software framework is set up, allowing for high-confidence tracking of all individuals over the entire lifespan of a honeybee colony. It is the first dataset ever collected (to our knowledge) that is extensive enough to provide a comprehensive view of a hive's life, maintaining the spatial, temporal and social context of the information it stores.

The data it collects can be put in 3 categories:

- a list of detections (each assigned to a bee, a point in time and a point in the hive space)
- a collection of individuals' paths (added in [X])
- and a collection of bee waggle dance occurrences (added in [X]).

The original *BeesBook* paper put significant focus on waggle dance research, but the dataset and collection method is meant to serve a very general purpose. The system is described to be "conceived as a budget-priced framework for the incremental development of software and hardware components", capable of supporting a wide range of investigations into invertebrates, the waggle dance, honeybee division of labor, collective intelligence and other related fields.

1.4 This work's goals

This work's primary goal is to add building blocks to the *BeesBook* project by deriving new abstractions that can be used in future analyses and to show how the process of deriving such abstractions could look like.

A secondary goal is to provide an example of how analysis could be undertaken in the future, given the data, the set of abstractions and the process for creating them.

Chapter 2

Related work

I present related work in three categories. The first one is an introduction to invertebrate tracking and automated observation, along with an overview of the state of the art.

The second focuses on the division of labor in honeybees. It's meant to set foundation for the analysis that we undertake in this work, as well as for determining what other kinds of approaches should be accessible given the BeesBook dataset and the building blocks that this work adds to it.

Finally, the last one collects works similar to this contribution - ones that use the *BeesBook* dataset to perform some analysis of a honeybee colony's life and/or add their own functionalities or improvements to the system.

2.1 Invertebrate observation and tracking

Observing invertebrates at scale, before a certain degree of automation was possible, required a lot of careful manual work and some creative approaches. A fascinating example of how experiments were conducted back then can be found in [4]. The authors mark a hundred bees out of a colony of 21 thousand, using a brush with pigment mixed with shellac (following the example set by Karl Von Frisch [6]). They then pick for observation small subsections of the hive (quadrants), employing the help of a Texas Instruments calculator to generate randomness for their choices. Inferences about the entire population are made using the samples, but even to observe the samples, 8 hours of continuous work per day, for over 20 days, was necessary. To create maps of activity, authors used glass sheets that they put markings on and exchanged every day. They then photographed the sheets and projected the photographs against a single sheet of paper, one by one, thereby aggregating the one-day information sets into a single map. They also used a number of other physical and numerical tricks to be able to produce quality data.

One step toward an automated process is to take video recordings and analyze them manually [3], also using markings, sometimes such that identifying a single individual from its marker was possible. This is less error-prone, but analysis of the film requires no less time than real-time observation (and often much more).

Compared to both those methods, modern approaches that analyze video footage automatically save a tremendous amount of effort. Researchers tend to take one of two paths: tracking the animals based on their previous positions and body features or using specialized markers (tags) that are put on individuals for identification.

A prominent and often-cited example in unmarked tracking is [2], where good results were achieved in tracking unmarked honeybees over short periods of time. They system employed was based on vector quantization and temporal contextual information. It was able to distinguish between individuals solely based on their body size and movement, keeping track of 50% of the hive (350 bees) over 10 seconds.

A recent notable work [1] reports maintaining 71% tracks for over 2 min, around 46% for 5mins (a 10^2 improvement). Such approaches are impressive technologically and of great importance by virtue of being generalizable (authors cite cells in tissues and human crowds as examples of potential usage); yet on the problem of invertebrate tracking do not yet achieve the results of marker-based systems in terms of effectiveness and scale.

They therefore do not allow for analysis that can draw conclusions relating to entire lifespans of individuals, as well as the colony (which is what I am attempting in this work). For anything related to foraging, systems based on trajectory and body features are particularly unreliable, as would lose track of individuals identities whenever they would leave the hive and come back.

Chapter 3

Introduction

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References

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[8] Williams, J. B., Roberts, S. P., and Elekonich, M. M. (2008). Age and natural metabolically-intensive behavior affect oxidative stress and antioxidant mechanisms. *Experimental Gerontology*, 43(6):538–549. 00096.

Appendix A

How to install LaTeX

Windows OS

TeXLive package - full version

1. Download the TeXLive ISO (2.2GB) from https://www.tug.org/texlive/
2. Download WinCDEmu (if you don't have a virtual drive) from http://wincdemu.sysprogs.org/download/
3. To install Windows CD Emulator follow the instructions at http://wincdemu.sysprogs.org/tutorials/install/
4. Right click the iso and mount it using the WinCDEmu as shown in http://wincdemu.sysprogs.org/tutorials/mount/
5. Open your virtual drive and run setup.pl

or

Basic MikTeX - TeX distribution

1. Download Basic-MiKTeX(32bit or 64bit) from http://miktex.org/download
2. Run the installer
3. To add a new package go to Start » All Programs » MikTex » Maintenance (Admin) and choose Package Manager

4. Select or search for packages to install

TexStudio - TeX editor

1. Download TexStudio from
   http://texstudio.sourceforge.net/#downloads

2. Run the installer

Mac OS X

MacTeX - TeX distribution

1. Download the file from
   https://www.tug.org/mactex/

2. Extract and double click to run the installer. It does the entire configuration, sit back and relax.

TexStudio - TeX editor

1. Download TexStudio from
   http://texstudio.sourceforge.net/#downloads

2. Extract and Start

Unix/Linux

TeXLive - TeX distribution

Getting the distribution:

1. TexLive can be downloaded from
   http://www.tug.org/texlive/acquire-netinstall.html.

2. TexLive is provided by most operating system you can use (rpm,apt-get or yum) to get TexLive distributions

Installation

1. Mount the ISO file in the mnt directory

   ```
   mount -t iso9660 -o ro,loop,noauto /your/texlive####.iso /mnt
   ```

2. Install wget on your OS (use rpm, apt-get or yum install)

3. Run the installer script install-tl.

   ```
   cd /your/download/directory
   ./install-tl
   ```

4. Enter command ‘i’ for installation

5. Post-Installation configuration:
   http://www.tug.org/texlive/doc/texlive-en/texlive-en.html#x1-320003.4.1

6. Set the path for the directory of TexLive binaries in your .bashrc file

For 32bit OS

For Bourne-compatible shells such as bash, and using Intel x86 GNU/Linux and a default directory setup as an example, the file to edit might be

```
edit $~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/i386-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

For 64bit OS

```
edit $~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/x86_64-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
```

```
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

Fedora/RedHat/CentOS:

```
sudo yum install texlive
sudo yum install psutils
```

SUSE:

```
sudo zypper install texlive
```

Debian/Ubuntu:

```
sudo apt-get install texlive texlive-latex-extra
sudo apt-get install psutils
```

Appendix B

Installing the CUED class file

LaTeX.cls files can be accessed system-wide when they are placed in the <texmf>/tex/latex directory, where <texmf> is the root directory of the user's TeXinstallation. On systems that have a local texmf tree (<texmflocal>), which may be named "texmf-local" or "localtexmf", it may be advisable to install packages in <texmflocal>, rather than <texmf> as the contents of the former, unlike that of the latter, are preserved after the LaTeXsystem is reinstalled and/or upgraded.

It is recommended that the user create a subdirectory <texmf>/tex/latex/CUED for all CUED related LaTeXclass and package files. On some LaTeXsystems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For TeXLive systems this is accomplished via executing "texhash" as root. MIKTeXusers can run "initexmf -u" to accomplish the same thing.

Users not willing or able to install the files system-wide can install them in their personal directories, but will then have to provide the path (full or relative) in addition to the filename when referring to them in LaTeX.