Genus for Protei

Introducing swarm behavior models for the fleet of Protei

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!Introduction

Protei is an open-source community aiming to develop a low-cost, efficient way for cleaning oil spills. Their means are to design unmanned, semi-autonomous (Or fully autonomous) sailing drones. A lot of research has already been performed, yet much research is still to be done. Our Wild Robots group has been working on many aspects of the Protei fleet. A few examples are innovative propulsion systems, DIY-building kits for personal use, development of autonomous boats, crowdsourcing for more development input from external users and swarm behavior.

The last aspect got my attention. I am fascinated by the fact that with just a few simple rules, entire swarms of animals can hunt together, protect themselves and so on. After a meeting with the Marine Department of Imtech, it became clear that developing proper swarm behavior takes a lot of man-hours. Years of man-hours. Protei's vision is to develop their boats quickly and as cheap as possible. So how can this be done? How can I make it so that swarm behavior development is done quickly, without too many costs?

This report describes the process performed by Pieter Bron in the Wild Robots project at the Faculty of Industrial Design, at the University of Technology, Eindhoven. His vision led him toward developing swarm behavior for Protei, an aspect that is able to combine PR for Protei and efficiency in the fleet of Protei. The entire project is divided into six design iterations. Not all iterations include swarm modeling, but the route toward swarm modeling is just as important.

Enjoy the report!

Pieter Bron

Protei

!

Objectives

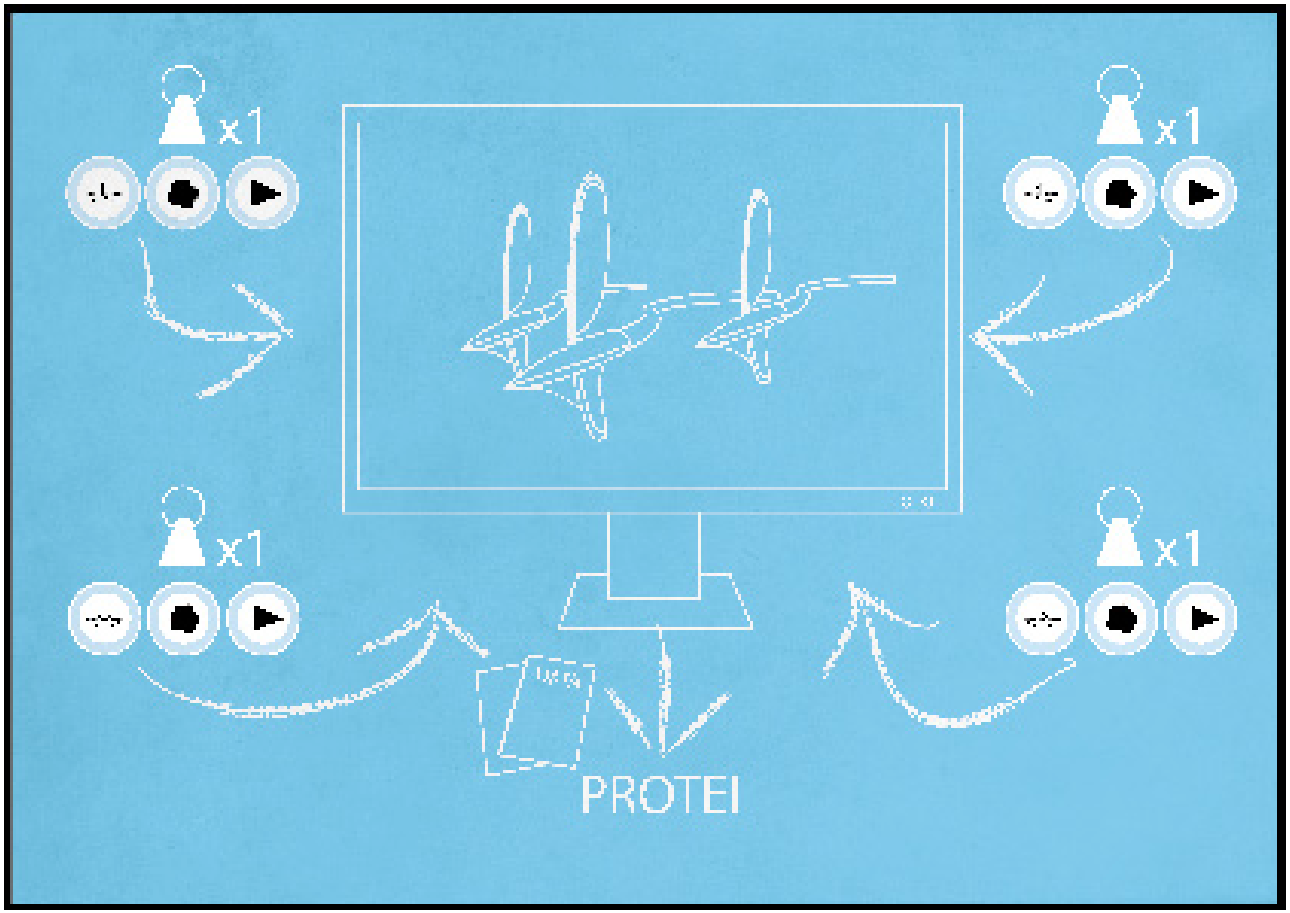
The ultimate goal for this project is to produce a cheap yet effective concept for swarm behavior for Protei. This platform should be open source and easy to use. Analythical data should also be transferred toward Protei to interpret different scenario's and their efficiency.

Specific questions that need to be answered are: "How can Protei effectively develop swarm models?" "How far should the user be able to influence the models?" "How does one pull data from the swarm models, and how is it provided to the Protei community?" "Who are possible testers?"

"But why swarm models?" - you might wonder. Throughout the next chapters, it will become clear why swarm behavior is so essential for Protei, and why it was only logical to start tackling this problem. It will show you the process from idea/concept toward building an actual swarm model, with all the design cycles in between. The program NetLogo is used for developing the swarm models. It is free, with a huge database of swarm model examples enabling new users to start quicker.

The focus throughout the entire project laid on the Gulf of Mexico, where recently BP had the large oil spill accident...

Open-Source Swarm Platform



! Design Brief

My personal direction for this project involves modeling of more advanced complex systems. Being someone who is able to lay connections very quickly, I want to really dive in the world of analyzing complex systems.

My weaker point is to communicate my ideas to other people. Therefore I want to put my focus on proper presentation as well. Working actively with an open-source community gives a great opportunity for representing myself.

On the midterm exhibition I want to have the boats finished which we are currently developing, and I want to start at the swarm modeling after the midterm.

The final exhibition should include working swarm models and a way of communicating data toward Protei. We should also combine everyone's efforts for Protei into one presentational model with a lot of aspects.

! Concept: Genus

Protei has one big advantage: It is open-source. This means that anyone can participate in their projects, and all information is freely available online. Taking on this advantage into swarm modeling has led toward many great opportunities. At the moment of writing, Protei is working on at least three aspects of the Protei community: Marketing/PR, Swarm Development and Boat Development. The problem with swarm development is that it requires a lot of testing, while Protei aims to keep things cheap and easy. Actual testing in the real world should therefore be avoided until there is no other option left. Genus creates this "other" option on swarm testing while it also provides an excellent marketing tool.

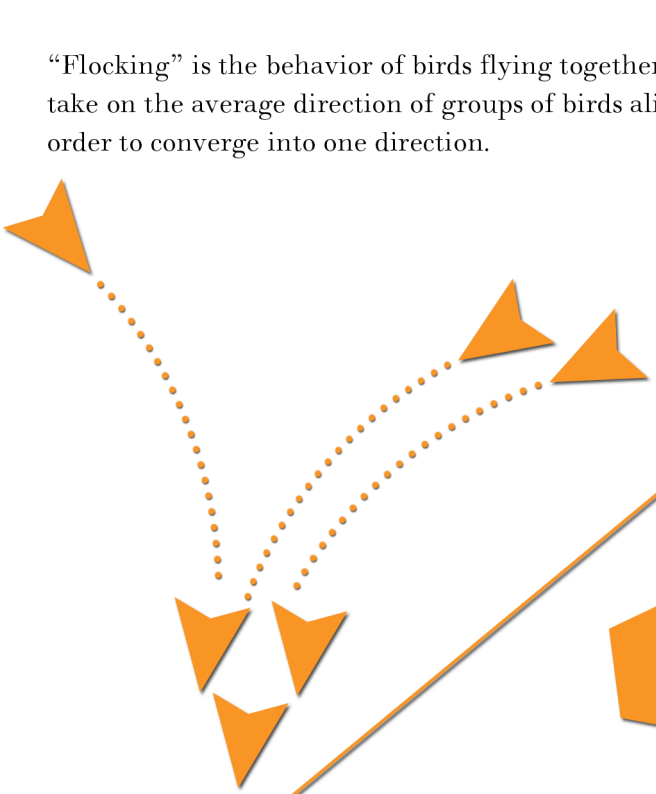
Genus is an online test-platform for Protei, based on NetLogo. You can visit it's first version here: http://pieterbron.nl/swarm/Swaaarm4.0.html

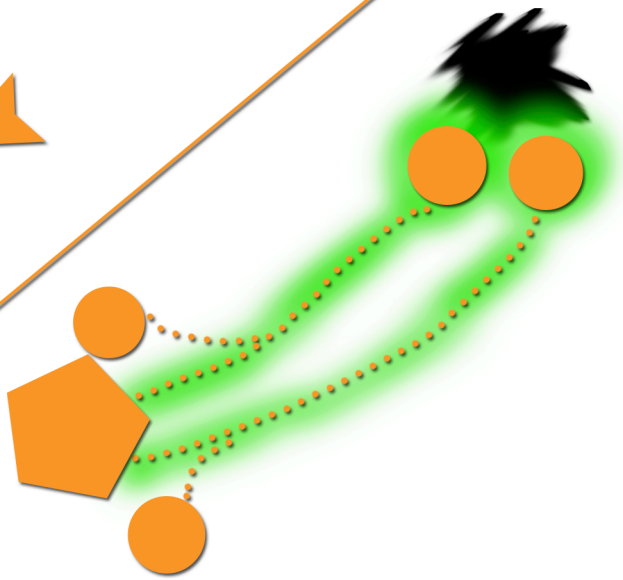
Any user can visit this site and give the swarm model a go. They can drop oil spills, they can add/remove boats, they can expand oil spills. The boats will start cleaning the oil according to specific patterns inspired by nature. The converging of boats is inspired by the flocking of birds (See picture), while the oil cleaning is done according to ant behavior. (Also see picture). This is only one type of model. If anyone wants to develop his/her own swarm model, you can download the entire package here: http://pieterbron.nl/swarm/Genus.zip. (Protei should also download this for further development.)

This kind of testing solves two problems at once: The amount of possible participaters is hugely increased, and it also creates a new marketing opportunity. By actively involving external users to co-test, Protei will receive more ideas and feedback on their swarms, resulting into better models for their fleet.

Base Model Swarm Behavior

"Flocking" is the behavior of birds flying together in V-shapes. They take on the average direction of groups of birds aligning together in order to converge into one direction.





Ants react on the scents left behind by other ants. The more scent, the more food that is available at one place. They continue gathering untill there is no scent left.

1 Exploration: Pressure Cooker

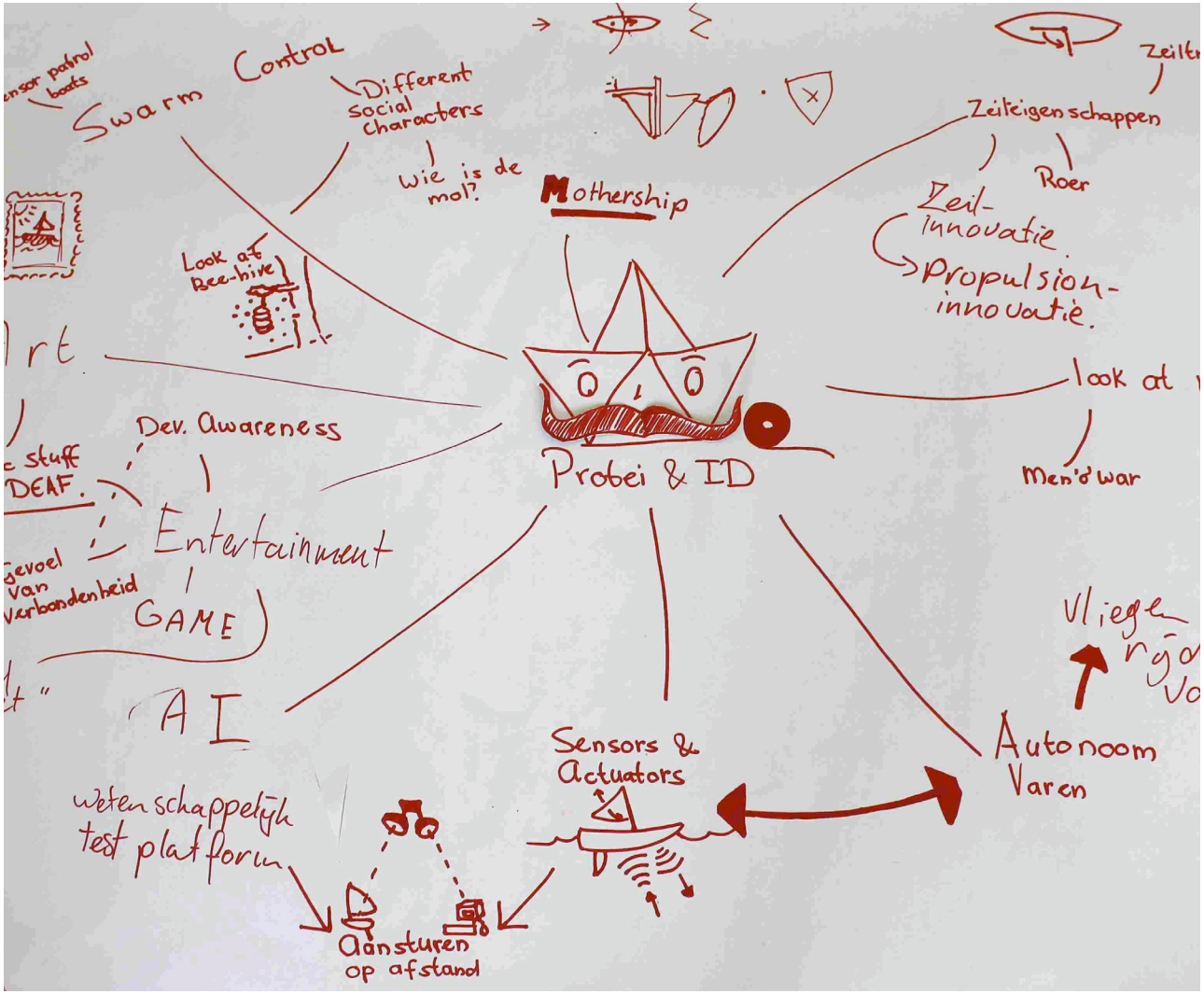
At the start of the project, the Wild Robots Industrial Designers started a collaborative pressure cooker. By going through a design cycle within a week, everyone quickly got entangled within the Protei project. It also became instantly clear what I wanted to do for Protei.

Further exploration went through hunting patterns of animals and other behavior in nature. There are some cases in the real world that already use these kind of swarm behavior in for instance aircraft landing schedules or delivery services. The train of thought with these models is using a decentralized system. Communism is a bit the same: Every individual is treated equally. Using decentralized systems is valuable for swarms of animals with low intelligence. Each individual is tasked with the same simple set of rules, yet as a group they can act quicker and more efficient compared to centralized systems with a hierarchy of importancy. A few examples are ants and birds: They have a simple set of rules on how to behave, yet together they work incredibly fast and accurate.

Given the context where the Protei fleet eventually has to work in, communicating with the fleet will be very hard and expensive. Overseas communication is one of the most expensive ways of communication, yet development in this area is also ongoing. (See http://www.rcc.uq.edu.au/vislab/sensornet/ for example)

Other encountered problems included the ever-changing water flows and wind directions. This resulted into the requirement that the boats can quickly adapt toward circumstances. In short: The boats should be capable of learning on top of a base model without interference from humans.

Brainstorm: Possible Directions



2 Requirements

In order for this prototype to work, all software needs to be open-source, so that anyone can use and alter it. Given the fact that Protei needs quantitative research here, with lots of statistics, the user group should be kept as large as possible. Therefore, it is wise to work with programs that are relatively easy to learn, while it should still be capable of producing advanced models.

The second iteration performed was a thorough research on what was essential for the swarm models, as well as what aspects of the context should be dealt with.

Lessons learned here are that nothing is changing more frequently than the ocean. There are animals to be taken into account, various types of weather and the water itself. Throughout all this, the boats have to be able to track down and gather oil using meters long "snakes" built of oil-absorbant material which trails behind the boats.

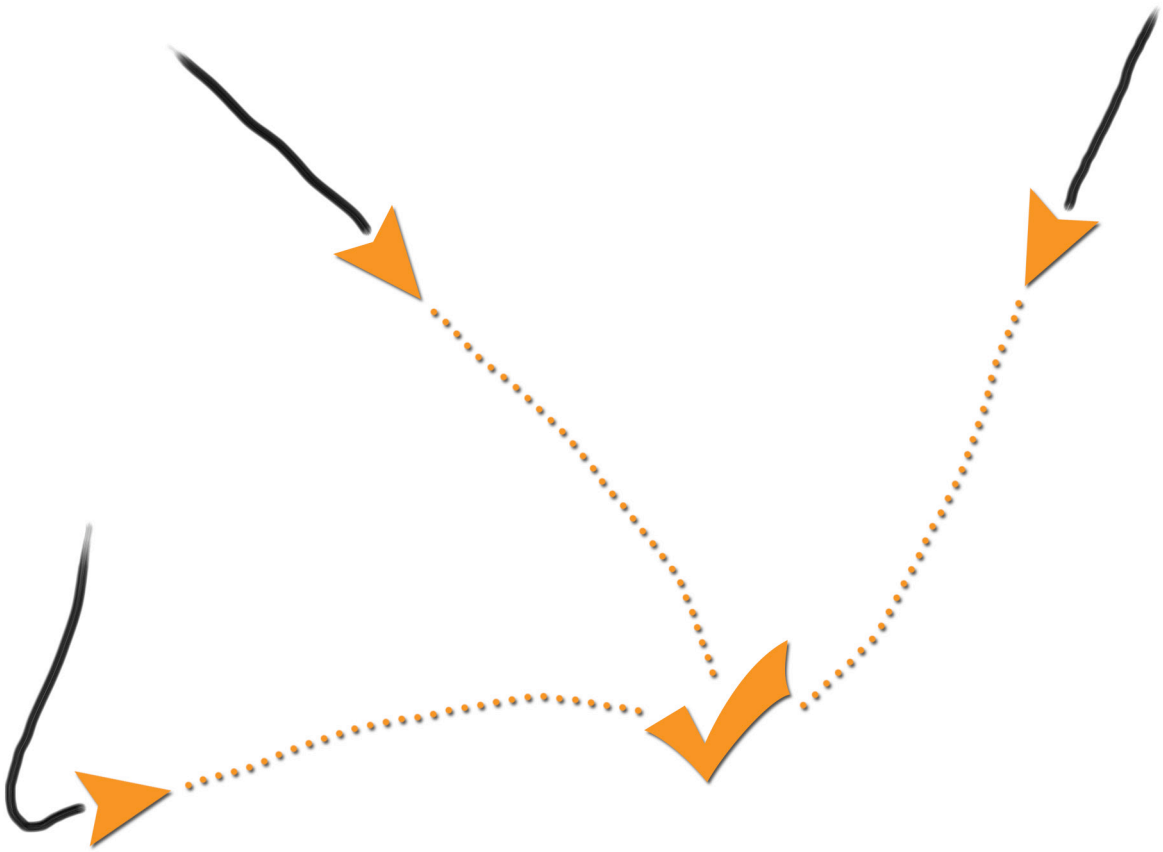
I came to the conclusion that every model should at least have:

- The first and most important rule that every boat should avoid collision with other objects AT ALL COST. We are trying to clean the ocean, not fill it with shipwrecks!

- The second rule that boats should eventually have a way to drop-off their oil somewhere. Eventually, the snakes will be filled with oil and they need to be swapped. Even though the system is decentralized, their should be a "nest" where the swarm can drop off it's oil.

Data gathered from these models should also be useful for Protei itself. A way of data gathering and visualizing statistics has to be found.

Return Oil To Central Point



3 Ideation

Some experiments were performed with various swarm modeling programs, but the conclusion eventually rose that NetLogo was really the best choice to go with. It has an easy-to-learn programming language, an open-source/minded community, an opportunity to create own plugins to link with NetLogo (Ideal for Data Gathering) while also possessing all the required objects for simulating Protei swarms.

NetLogo basically works with four types of objects:

- An Observer
- Turtles
- Patches
- Lines

The observer tells all other objects what to do. This is the actual controller of the model. (So yes, there is some sort of hierarchy in the model..) The Turtles are moving agents that carry out tasks instructed by the observer. Patches are squares of land, each with it's own coördinate and properties. Lines are connections between Turtles.

For the base swarm model to work, a set of "Protei boats" had to be created. The patches would then be divided in water and oil.

Paired with the flocking behavior of birds, the first model worked quite well, right until the oil was eventually found. The boats were unable to really start gathering oil. They just floated right through it and sailed away from it.

The idea then rose to mind to introduce scent, just like ants do it. The idea is simple: When a bit of oil is found, the boat spreads a "scent", alarming other boats to gather around and start cleaning the oil too.

This can be done using two methods:

- The oil, as soon as it appears on the water, spreads a “scent” in all directions. There are oil sensors available nowadays, with an effective range of approx. 100 meters. In effect this would mean that every boat will be equipped with oil sensors, and as soon as oil is spotted, they’ll float toward it.

- As soon as a boat encounters oil and starts cleaning it, the boat itself sends a signal across the ocean, telling other boats that there was oil at a specific spot. The range for this type of communication is further, yet still not optimal.

Luckily, Roel and Paul came up with a visionary idea..

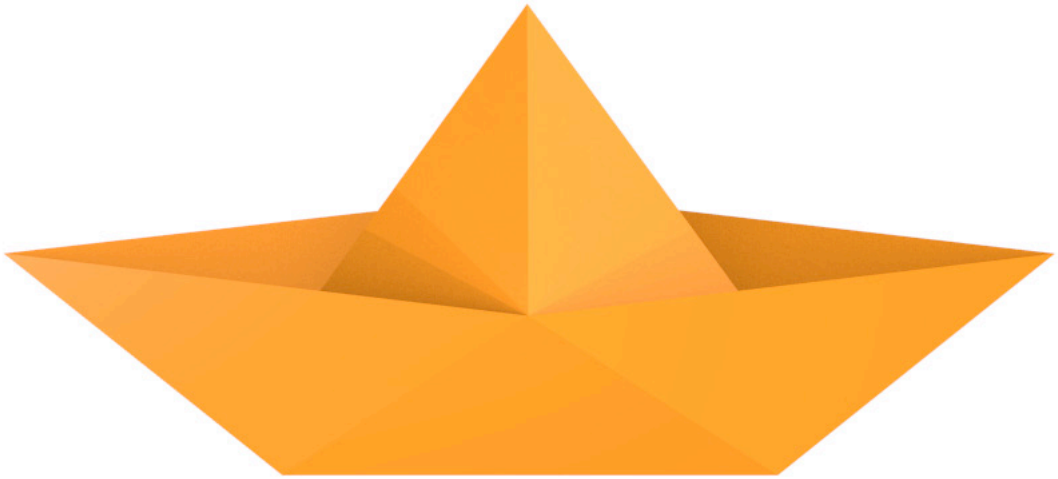
4 Species

By approaching Protei as a specie, our Wild Robots group was able to set-up a concrete platform to further develop our concepts upon. Until this moment, Protei has been quite abstract as to how they'd want to further develop the fleet. Iterations in various directions were already performed (Propulsion, oil sensing, location of oil spills.), yet a concrete plan for developing the swarms wasn't available yet.

With this innovative idea, a platform was succesfully created, and it hugely sped up our progress. It also changed my train of thought on the swarms. I started treating the swarm with animalistic behavior, rather thinking about what an animal would do instead of a robot.

Paul & Roel's research showed that it would be most efficient to have some kind of "mothership" sailing along with the swarm, where humans work and where oil is extracted from the boats. This would also ensure that damaged boats can be repaired relatively easy. More importantly, it is a more viable way for my swarm models to work as well. The Mothership can now be seen as a "Nest" where the boats return to after it's tail is full. There, the boats can exchange "scents" with each other to spot oil spots. This can be easily achieved by using GPS-trackers.

Species!



Protei Fleet as Specie: Genus

5 Imtech, DEAF

Piem Wirtz (From V2, Rotterdam) arranged an expert-meeting for us with Imtech Rotterdam, Marine Specialists. Piem showed some of our work to Mart Hurkmans, coordinator R&D at Imtech. Imtech is currently working on a project involving autonomous sailing drones. They want to become a beacon inside the autonomous world. There have been many (small) projects involving autonomous boats, yet a concrete workflow is not present yet. Imtech wants to couple all these projects together and become the main database. They want to unite rather than contest.

For me it was really valuable to hear this outcome. This meant that my concept would be very valuable toward Imtech as well! An open-source testing platform concerning swarm behavior can be greatly exploited by specialists from Imtech, for example.

I started building swarm models for real after this meeting with Imtech. Preparations for DEAF were also performed.

Various important member of the Protei community were present at DEAF. Protei was present to show their sixth iteration to the world, a six meter long sailing drone. An informal exhibition was scheduled with 15 minute long sessions where we could also present our work. All aspects of our Wild Robots project were actively elaborated on.

Cesar Harada's suggestion for Genus was to think of a second layer above the swarm model to analyze data. It is one thing to show the models which are working, but it's a much more valuable thing to show statistics on these models.

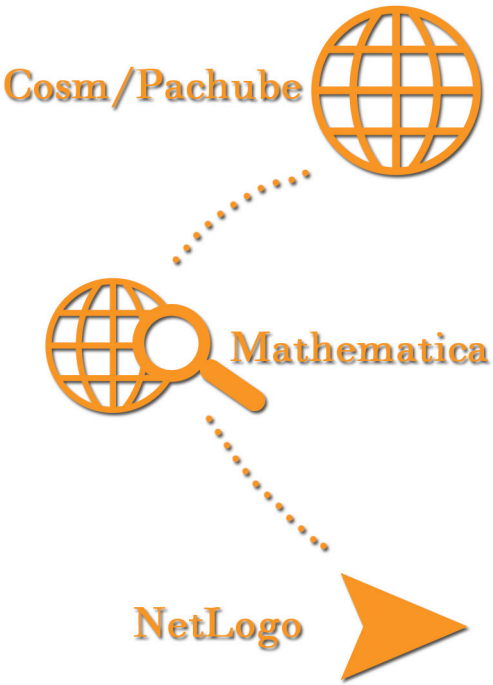
6 Data Gathering

Due to time shortage, the real link for data gathering isn't set-up yet, though research in the area has been performed.

The chain of programs that is probably the best way for extracting data from the models and converting it into statistics is the following:

- NetLogo -> Mathematica Link. Freely available at the NetLogo website. Mathematica comes with commands which analyzes the NetLogo models such as: "Show amount of turtles after X amount of time" or "Show amount of time to clean the oil".

- Mathematica -> Cosm/Pachube. Cosm/Pachube is a data gathering program which is able to convert streams of data into statistics. (See http://www.cosm.org) It creates an online platform with an easy overview, ideal for Protei.



Recommendations

If one wants to take on this project and further develop it, they should by all means feel free to download my swarm model. I can help them set-up a testing environment online.

Further development should include:

- A concrete way to transmit data to mathematica & COSM. Few work has been performed to get it to work in Mathematica.

- User-testing. Small scale user-testing has already been performed, yet large scale testing is still to be done.

Acknowledgements

I want to thank the following person in particular:

- Sam Nemeth -
To support me through thick and thin. Times have been hard for me, yet he kept me going.

- Etienne Gernez -
For being such a great guy, always enthusiastic and happy minded. For his great communication between us and the Protei community. For being the happy face on the friday morning!

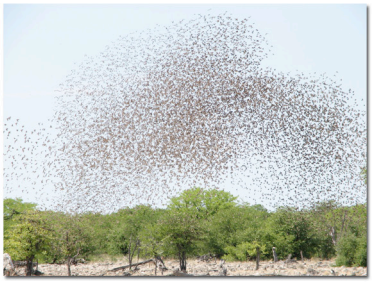
- Mart Hurkmans -
For allowing us to engage in a meeting with Imtech.

- Piem Wirtz -
For connecting us with Imtech. For introducing us to the Protei community and explaining us how the Protei community is currently working.

- Cesar Harada and Sebastian Müllauer -
For meeting us at D.E.A.F. I want to especially thank them for their suggestions upon improving the data gathering for my models. (Cosm). For showing great enthusiasm toward my project.

- My fellow students -
For showing great support throughout the semester. Without them, I wouldn't have gone far.

A Appendix. A
Hunting Patterns



Birds fly in a flocking pattern.
They converge and align, taking on the average direction of the flock.

Cons:
- Sacrifice feeding efficiency

Pro's:
- Increased foraging efficiency
- Safety in numbers

Conclusion: Behavior is useful for scouting the area.

Ants gather food efficiently using pheromones.
They follow trails laid by other ants.

Cons:
- Sacrifice area scouting

Pro's:
- Increased gathering efficiency
- Safety in numbers
- Simple tasks, efficient behavior.

B Appendix. B
Source Code

The source code for my swarm model in NetLogo.

```
turtles-own [
  flockmates
  nearest-neighbor
  ]

patches-own [
  countdownpatch
  oil?
  oil-scent
  nearest-oil
  oilset
  ]

to setup
  clear-all
  setup-turtles
  reset-ticks
  setup-patches
  ask patches [
    set countdownpatch oil-respawn-time
  ]
end

to go
  move-turtles
  eat-oil
  tick
end

to setup-patches
  ask patches [ set pcolor 106]
end

to setup-turtles
  create-turtles amount-of-turtles-to-add
  ask turtles [ set size 25 set shape “sailing-
boat” ]
end
```

```
;;;;;;;;;;;;;;;;;;;;;;;;; FLOCKING of BOATS ;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to move-turtles
  ask turtles [
    set pen-size 3
    flock
    fd 1
    rt random 5
    lt random 5
    uphill-oil-scent
  ]
;;  ask turtles [
;;  if (distancexy 0 0) > 270
;;    [ right 180 ]
;;  ]
end

to flock  ;; turtle procedure
  find-flockmates
  if any? flockmates
    [ find-nearest-neighbor
      ifelse distance nearest-neighbor < 25
        [ ]
        [ align
          cohere ] ]
end

to find-flockmates  ;; turtle procedure
  set flockmates other turtles in-radius 50
end

to find-nearest-neighbor ;; turtle procedure
  set nearest-neighbor min-one-of flockmates
[distance myself]
end

;;; ALIGN

to align  ;; turtle procedure
  turn-towards average-flockmate-heading 2
end

to-report average-flockmate-heading  ;; turtle
procedure
  ;; We can't just average the heading variables
here.
  ;; For example, the average of 1 and 359
should be 0,
  ;; not 180.  So we have to use trigonometry.
  let x-component sum [dx] of flockmates
  let y-component sum [dy] of flockmates
  ifelse x-component = 0 and y-component =
0
    [ report heading ]
    [ report atan x-component y-component ]
end
```

```
;;; COHERE

to cohere  ;; turtle procedure
  turn-towards average-heading-towards-
flockmates 10
end

to-report average-heading-towards-flockmates
;; turtle procedure
  ;; "towards myself" gives us the heading
from the other turtle
  ;; to me, but we want the heading from me
to the other turtle,
  ;; so we add 180
  let x-component mean [sin (towards myself
+ 180)] of flockmates
  let y-component mean [cos (towards myself
+ 180)] of flockmates
  ifelse x-component = 0 and y-component =
0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; HELPER PROCEDURES

to turn-towards [new-heading max-turn]  ;;
turtle procedure
  turn-at-most (subtract-headings new-hea-
ding heading) max-turn
end

to turn-away [new-heading max-turn]  ;;
turtle procedure
  turn-at-most (subtract-headings heading
new-heading) max-turn
end

;; turn right by "turn" degrees (or left if
"turn" is negative),
;; but never turn more than "max-turn" de-
grees
to turn-at-most [turn max-turn]  ;; turtle
procedure
  ifelse abs turn > max-turn
    [ ifelse turn > 0
        [ rt max-turn ]
        [ lt max-turn ] ]
    [ rt turn ]
end

;;;;;;;;;;;;;;;;;;;;;;;; PLACEMENT of OIL ;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to drop-oil
  ask patch oil-place-x oil-place-y [ set pco-
lor black ]
end
```

```
to setup-oil-scent
 ask patches[
 if pcolor = 106 [
  find-nearest-oil
  if distance nearest-oil < 20 [
  set oil-scent 20 - distance nearest-oil
 ]
 ]
 ]
end

to find-nearest-oil ;; patch procedure
 if any? patches with [oil-scent = 20] [
 set nearest-oil min-one-of patches with [pco-
lor = black] [distance myself]
 ]
end

to spread-oil
 ask patches [
  if pcolor = black [
   ifelse countdownpatch <= 0
    [
   ask patch-at random 1.1 1.1 [
    set pcolor black
    set oil-scent 20
   ]
   ask patch-at random -1.1 -1.1 [
    set pcolor black
    set oil-scent 20
   ]
   ask patch-at random -1.1 1.1 [
    set pcolor black
    set oil-scent 20
   ]
   ask patch-at random 1.1 -1.1 [
    set pcolor black
    set oil-scent 20
   ]
   set countdownpatch oil-respawn-time
   ]
   [ set countdownpatch countdownpatch - 1
]
  ]
 ]
end

;;;;;;;;;;;;;;;;;;;;;;;;;; EATING of OIL ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to eat-oil
 ask turtles [
  if pcolor = black [
   set pcolor 106
   set oil-scent 0
  ]
 ]
end
```

```
to uphill-oil-scent  ;; turtle procedure
  let scent-ahead oil-scent-at-angle   0
  let scent-right oil-scent-at-angle  45
  let scent-left  oil-scent-at-angle -45
  if (scent-right > scent-ahead) or (scent-left
> scent-ahead)
  [ ifelse scent-right > scent-left
    [ rt 45 ]
    [ lt 45 ] ]
end

to-report oil-scent-at-angle [angle]
  let p patch-right-and-ahead angle 1
  if p = nobody [ report 0 ]
  report [oil-scent] of p
end
```