Collective Intelligence (集合知) and Artificial Life (人工生命)

Hikawa High School, Yamanashi, Japan
JSPS Science Dialogue Program

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Japan Society for the Promotion of Science
日本学術振興会

東京大学
THE UNIVERSITY OF TOKYO

Programme outline

I. Brief introduction to Collective Intelligence by Horiguchi-san (in Japanese)

II. Self-introduction and academic background

   i. Who am I?

   ii. Why did I come to Japan?

   iii. How did I become interested in ALife research?

Break

III. Research into Collective Intelligence

   i. What is Collective Intelligence?

   ii. Exploring mechanisms for collective intelligence (current research)

Brief introduction to **Collective Intelligence**

集合知とは

Self-introduction

Who am I?

みなさん、こんにちは！My name is Michael and I am:

- 32 years old（born 1992, 平成4年）
- I grew up in Devon, England (イギリス南西部)
- In my spare time, I enjoy hiking (ハイキング), reading (読書), video games (ビデオゲーム) and studying Japanese (日本語勉強中)

よろしくお願いします！

I have been living in
Japan for 2+ years

Population (人口)

67 million 🇬🇧 🇯🇵 **125 million**

6700万 – 1億2500万

Land mass (陸地面積)

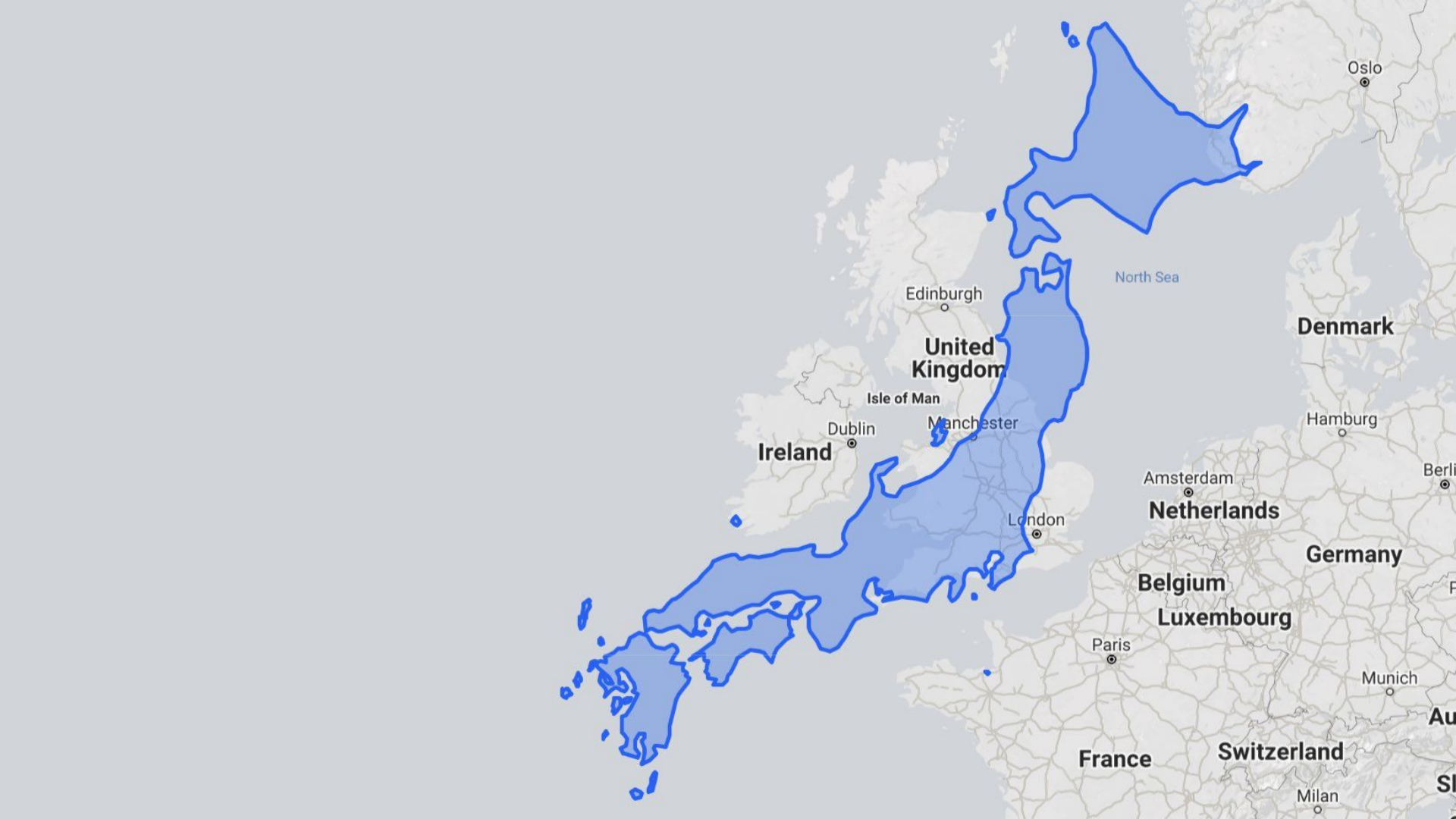
243,000 km^2 🇬🇧 🇯🇵 **378,000 km^2**

Rainy days ☔ (雨の日)

152 days 🇬🇧 🇯🇵 118 days

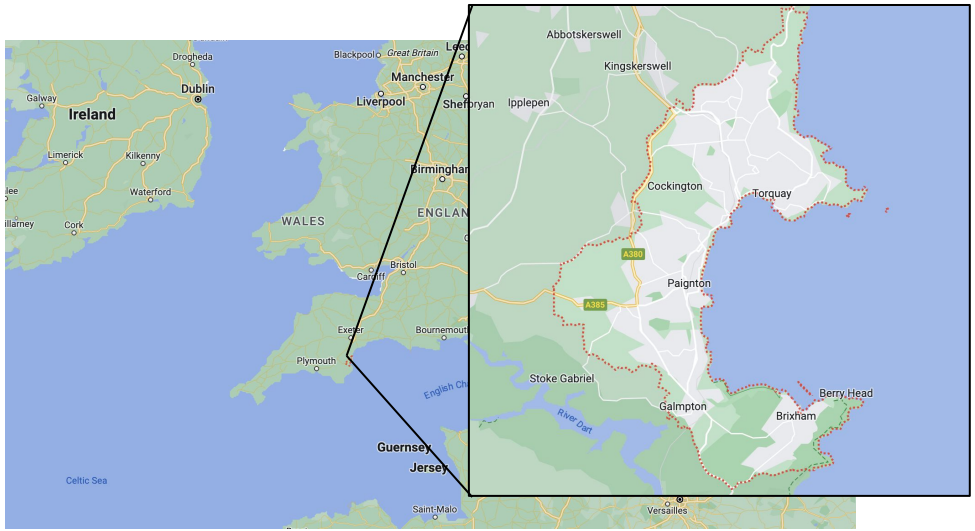
Sunshine hours (日照時間)

1,351 h 🇬🇧 🇯🇵 **1,935 h**

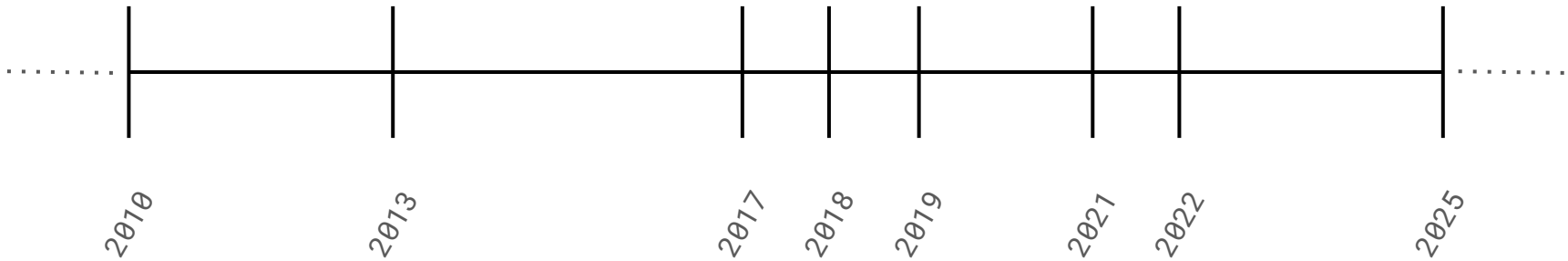

Oslo
North Sea
Edinburgh
Denmark
United Kingdom
Isle of Man
Hamburg
Dublin
Manchester
Ireland
Amsterdam
Netherlands
London
Germany
Belgium
Luxembourg
Paris
Munich
France
Switzerland
Milan

Where am I from?

- I grew up in the small town of **Torbay, Devon**, as did my parents.
  - Torbay has a population of ~130,000 (13万人)
  - I grew up by the beach, so now I don’t like beaches



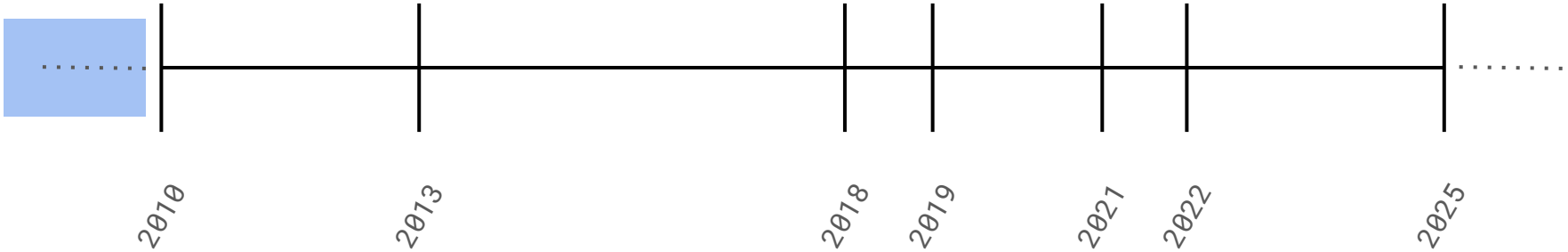
What was my academic journey?



What was my academic journey?

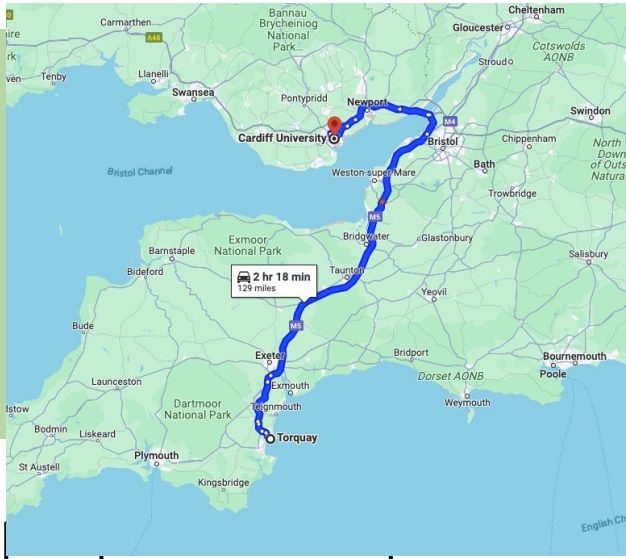
- < 16歳: Not a serious student, rarely studied
- 16-18歳: Studied hard, grades went from C → A
- I loved essay subjects (Philosophy 哲学, History 歴史)

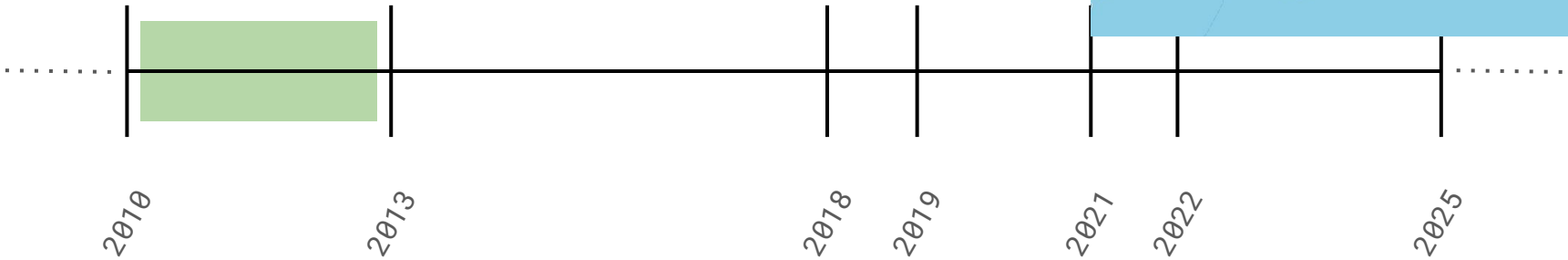
- But, I was really interested in computers, so…

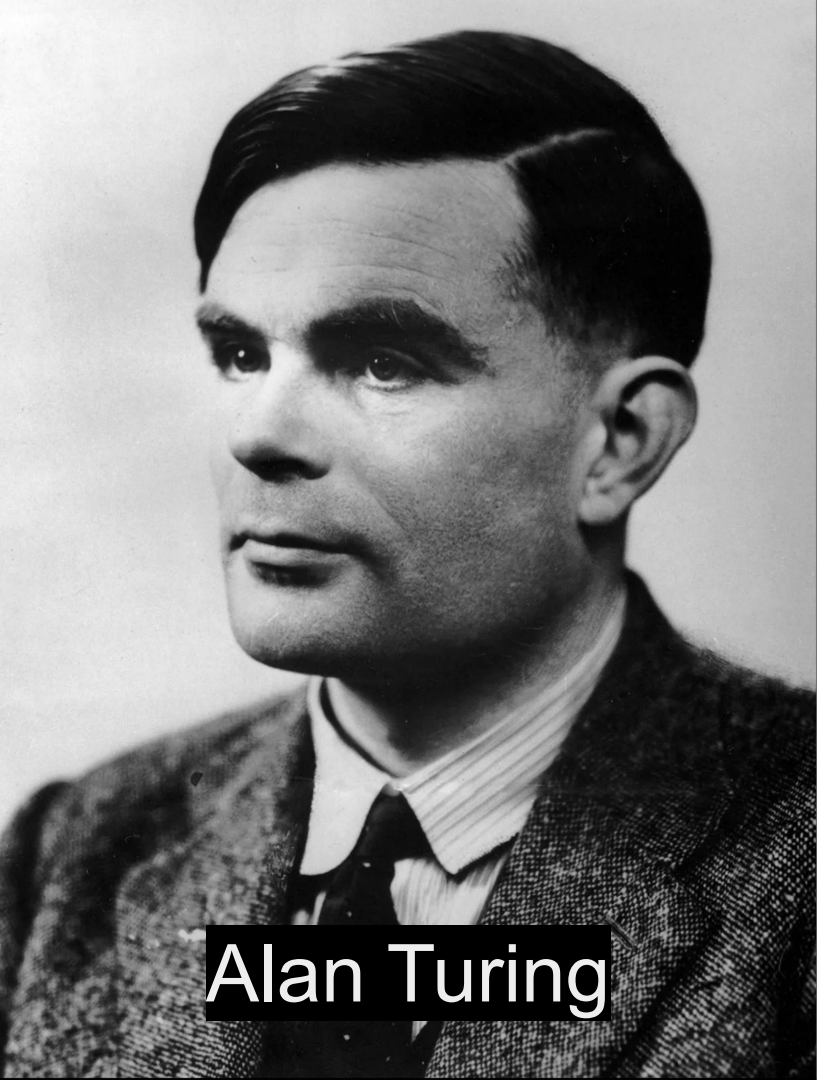


What was my academic journey?

- I decided to go to university
- Studied Computer Science at Cardiff University
- First Class Honours degree
  - Enabled me to receive a PhD scholarship.

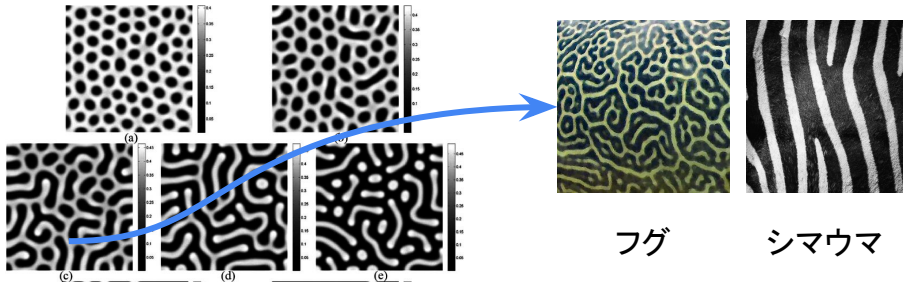






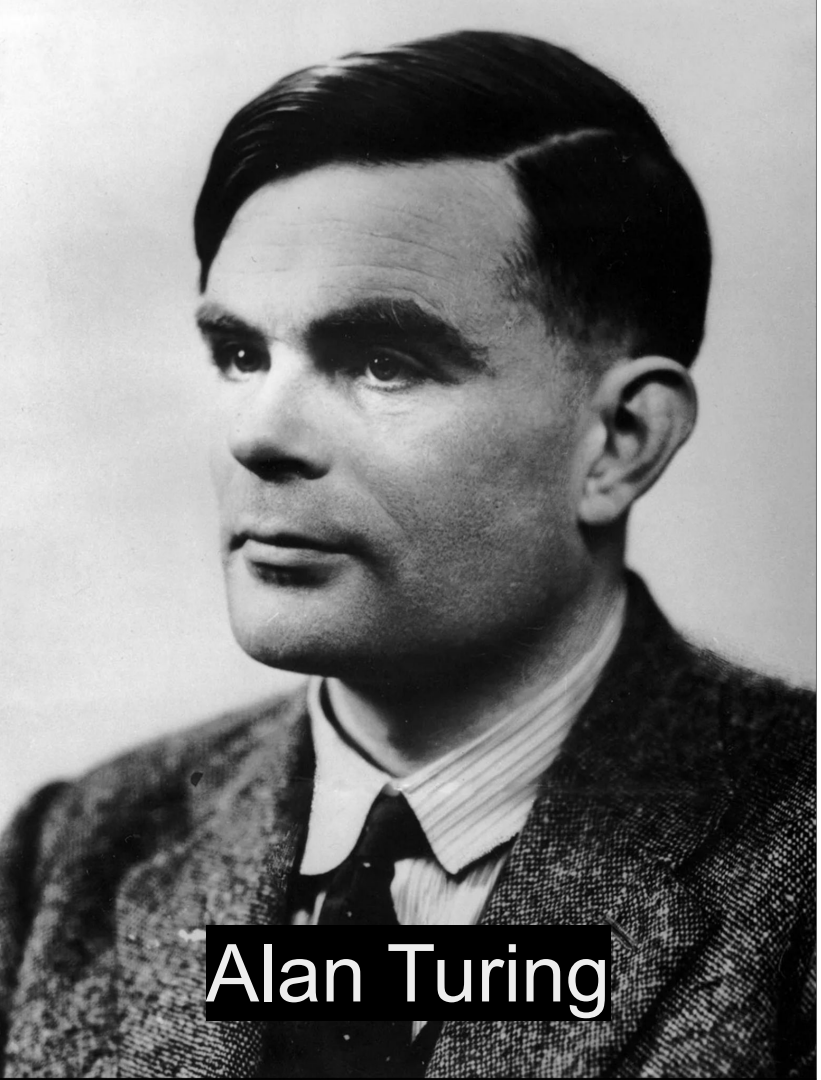
To me, he was inspirational as a:

- Mathematician (数学者/論理学者)
- Cryptanalyst (暗号解読者)
- **Computer Scientist** (コンピュータ科学者)
  - Invented the “Turing Machine” (チューリング機械)
- Theoretical Biologist (理論生物学者)

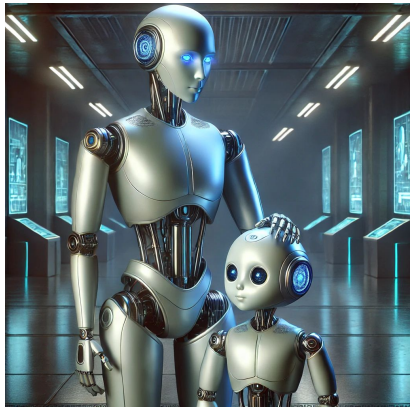


チューリング・パターン

Turing built a model to explain how patterns in nature arise from chemical reactions.



Turing also introduced the concept of a “**Learning Machine**” (学習機械)



人間レベルの知能を作り出すのは難しい

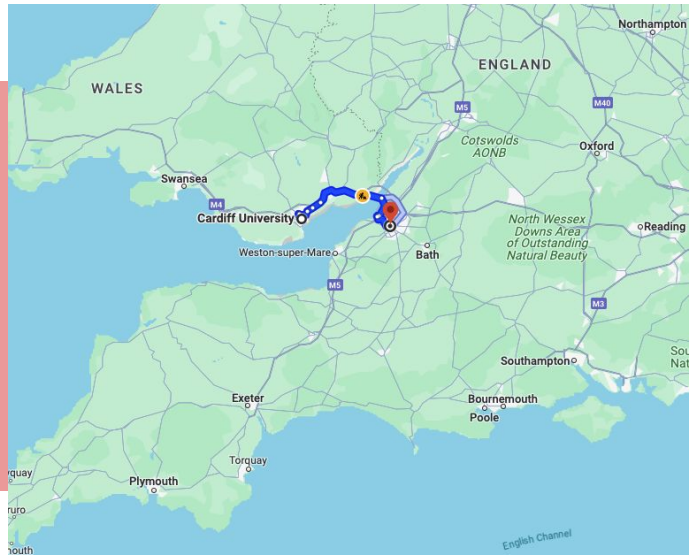
チューリングは「子供のようなロボットから始めて、学習し知能を発達させる方が簡単だと思う」と言った

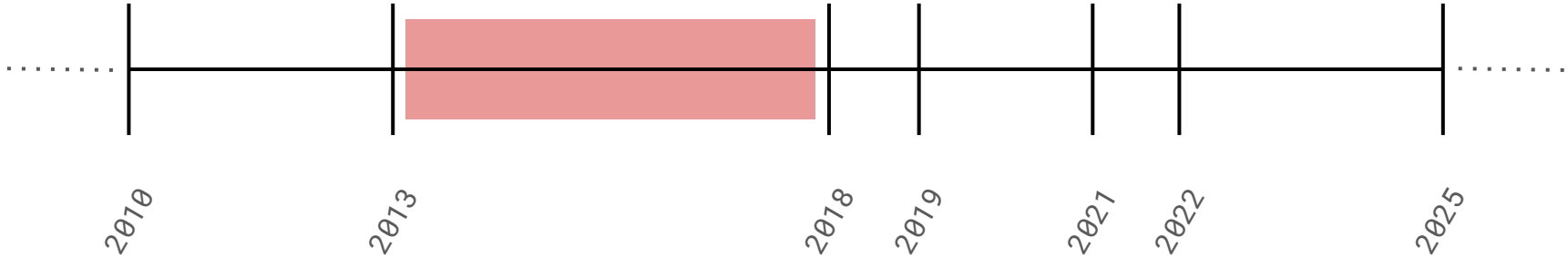
He is considered to be a **founding father** of **Artificial Intelligence**.
アラン・チューリングは人工知能の創始者の一人とみなされている

Turing taught me to stay curious!
私に好奇心を持ち続けるよう教えてくれた！

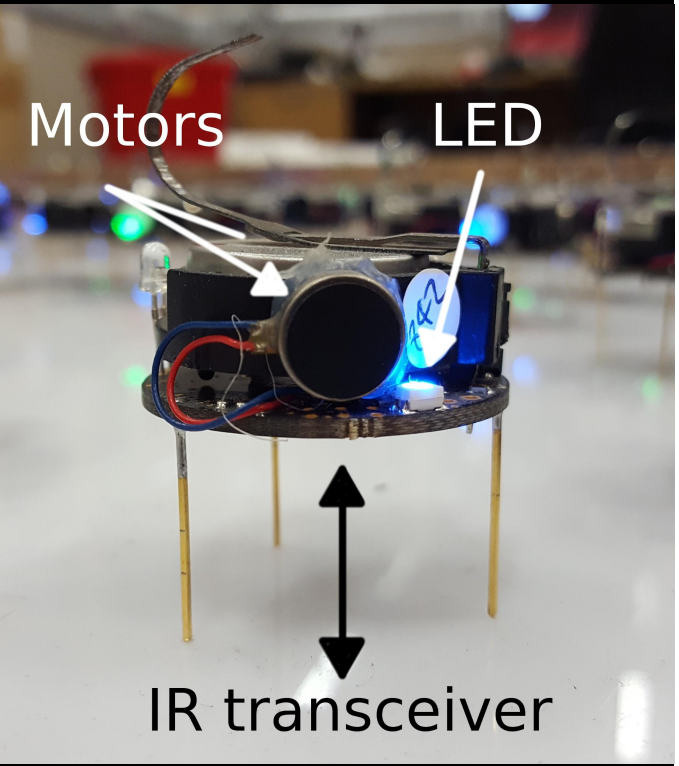
What was my academic journey?

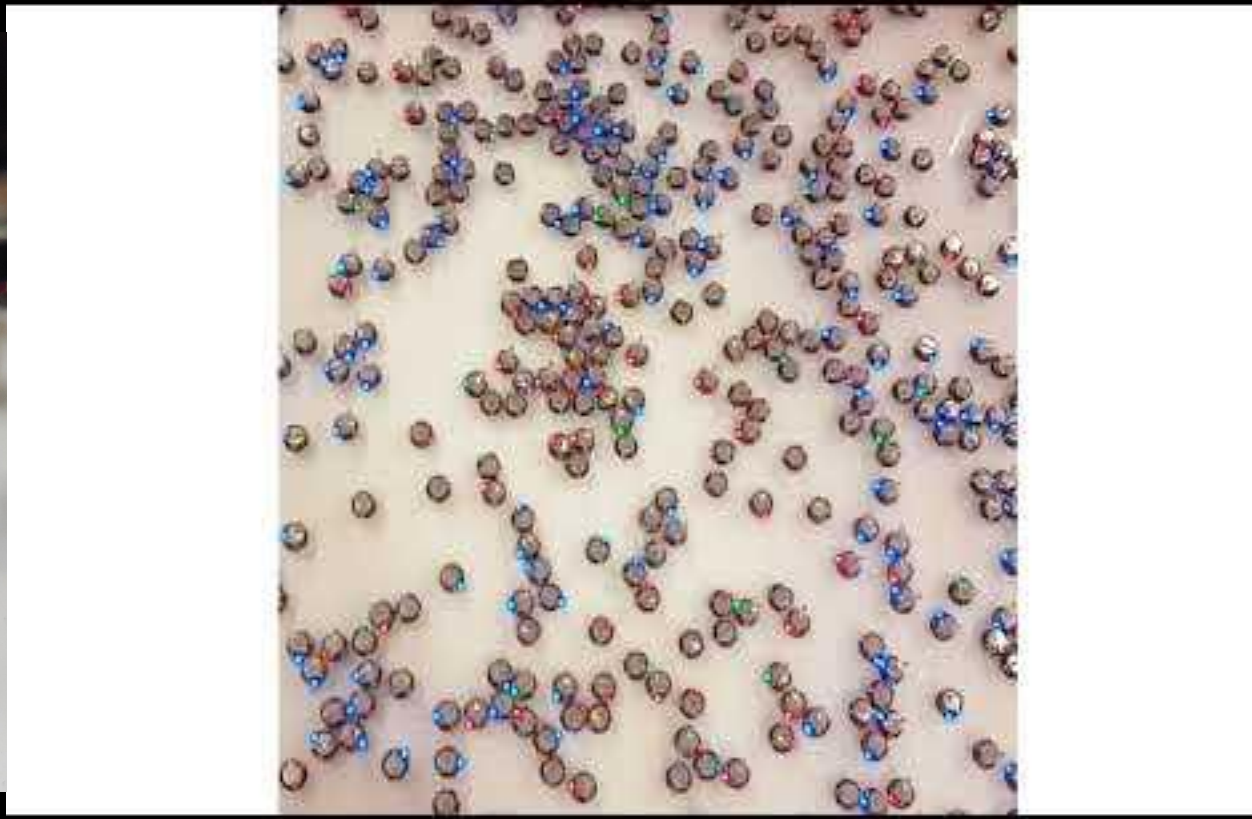
- Began PhD in Engineering Mathematics at the University of Bristol
- I was interested in Artificial Intelligence
- Discovered interest in multi-agent systems, robot swarms





Kilobot: 一線ロボット



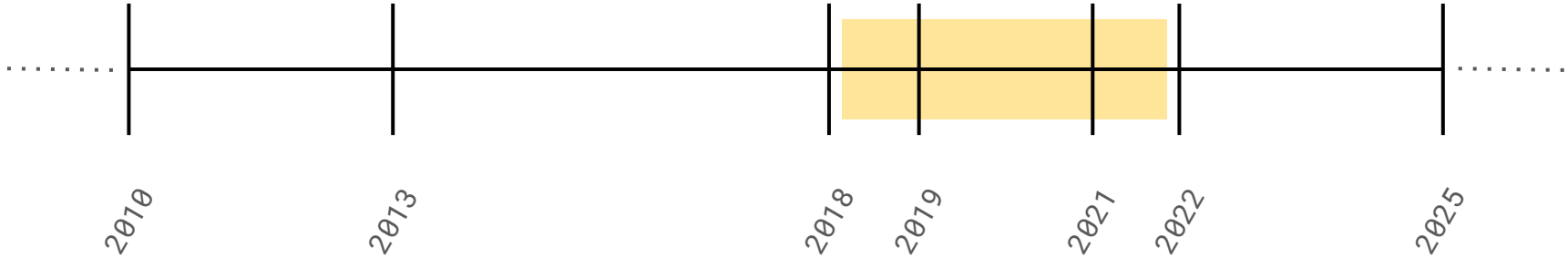


Research conducted during my PhD in ~2016.

What was my academic journey?

- After PhD, I worked as a postdoctoral researcher (研究者) I wanted to move into a different field of research, but what?
- In **2019**, I attended a conference in Okinawa about SWARMS (群れ), and a workshop on ALIFE

- I attended the **ALIFE 2020** virtual conference →



Applying to JSPS – Moving to Japan

- At that conference, I (virtually) met some Japanese researchers in the field
- One person was creating “generative art” inspired by ALife
- I decided to contact a professor working on ALife and applied to work in Japan via

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE
日本学術振興会

- Luckily I was accepted, and so in May, 2022, I moved to Japan to research a new topic in a new field, in a new country

Mitsuyoshi

Ikegami lab

Prof.
Ikegami

Summer camp
Ito, Shizuoka
August, 2023

Mt. Tateshina, Yatsugatake (Nagano/Yamanashi border) – 🇯🇵 2,531 m

The United Kingdom's tallest mountain, Ben Nevis, is just 🇬🇧 1,345 m tall and is in located in Scotland

Japan has *many, many* mountains taller than mountains in the UK

End of Self-Introduction

Ongoing research:

COLLECTIVE INTELLIGENCE

Collective Intelligence

Previously, I developed nature-inspired algorithms for robot swarms

Now, I want to understand the mechanisms of intelligent collective behaviours

How do we define collective intelligence?

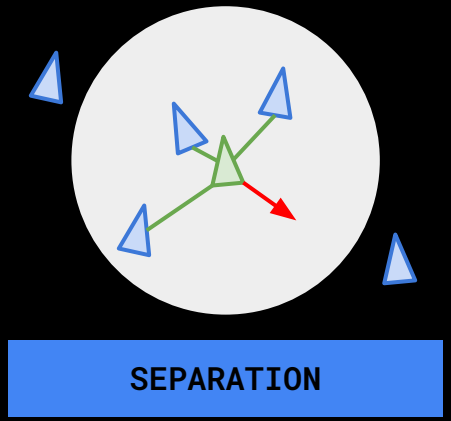
- I think intelligence is collective (集団的) in nature
  - *We learn most effectively through **interacting** with each other*
- Collective intelligence is an emergent phenomenon (創発現象)
  - ***Interactions** between individuals produce new behaviours in the collective*

Interaction = 交流

National Geographic

Flight of the Starlings

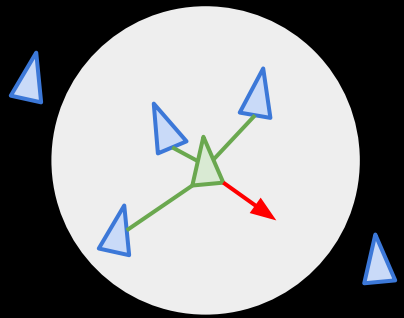
Building a model (Craig Reynolds, 1986)



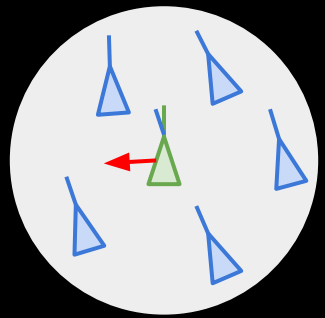
分離: 混雑を避けるように操縦する

[Boids - Wikipedia]

Building a model (Craig Reynolds, 1986)



SEPARATION

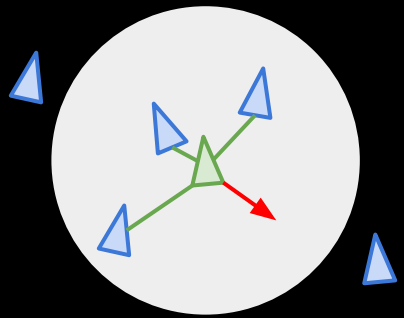


ALIGNMENT

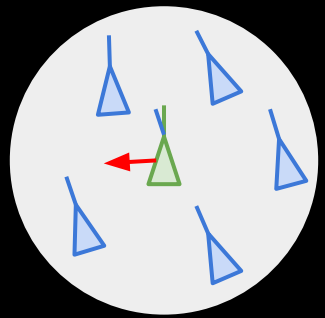
整列: 他の個体の平均的な進行方向に向かって操縦する

[Boids - Wikipedia]

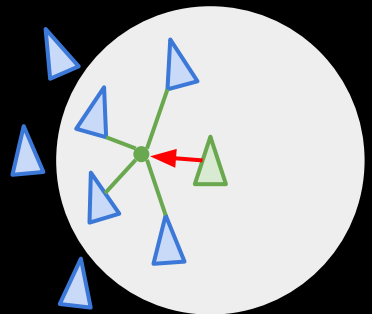
Building a model (Craig Reynolds, 1986)



SEPARATION



ALIGNMENT



COHESION

結合: 重心に向かって移動するように操縦する

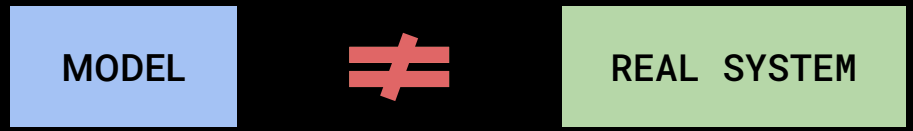
[Boids - Wikipedia]

Large scale boids (Maruyama et al. 2019)

500,000 boids (50万)

Models of Collective Intelligence

This model works well to reproduce the *real* collective behaviour, however…



Models are useful for learning more about a system, but…

モデルはシステムについてより深く学ぶのに役立つが

It is difficult to capture *all* of the details about the system

システムの「すべて」の詳細を捉えるのは難しい

“All models are wrong, but some are useful” – George Box

すべてのモデルは間違っているが、いくつかは有用である。　　モデルを作ろう！

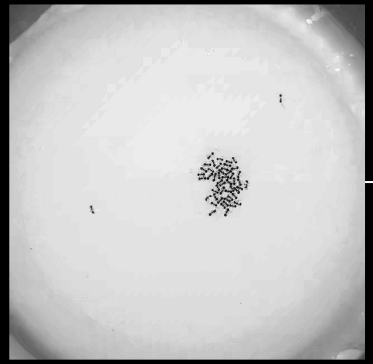
Ants: An Intelligent Collective

64 Pristomyrmex punctatus Ants
(Dobata Lab @ UTokyo, 2023)

1. No queen
   女王アリはいない
2. Female workers lay eggs through asexual reproduction
   雌の働きアリが無性生殖で卵を産む
3. Cluster instead of building a nest
   アリは巣を作る代わりに集まる
4. Younger ants lay eggs, older ants forage
   若いアリは卵を産み、年上のアリは餌を探しに行く

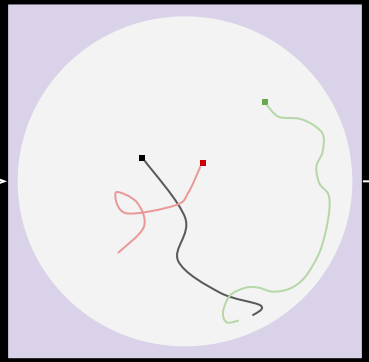
Note: No leader, all of the ants are self-organising (自己組織化).

We begin by creating a dataset (データ集合)



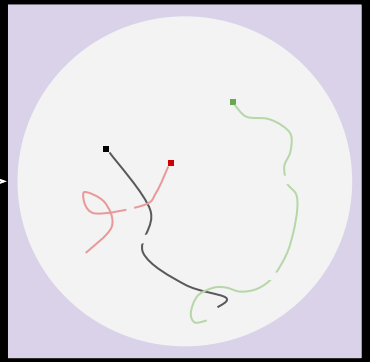
Video recordings

ビデオ録画



Extracted ant trail data

抽出されたアリの経路データ

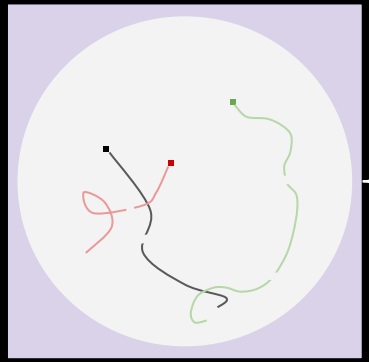


Short sequences of behaviour

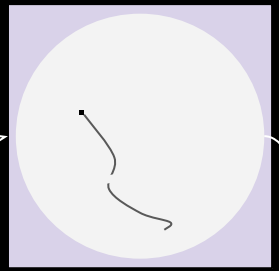
短期的な行動パターン

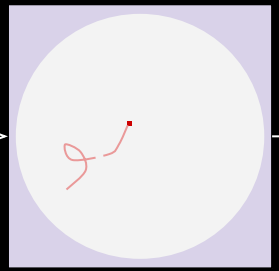
10-60 seconds?

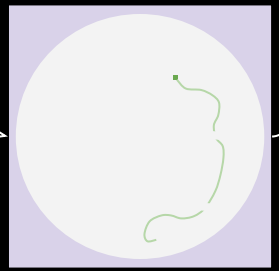
Then we evolve a model of behaviour

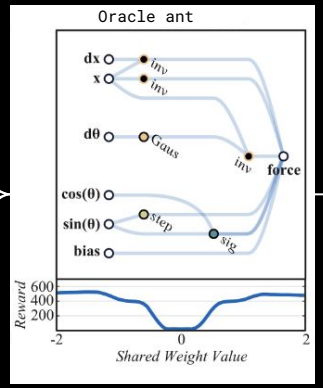


Short sequences of behavioural dynamics

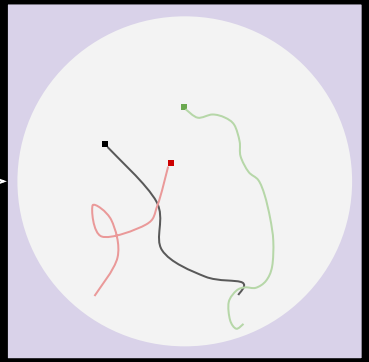






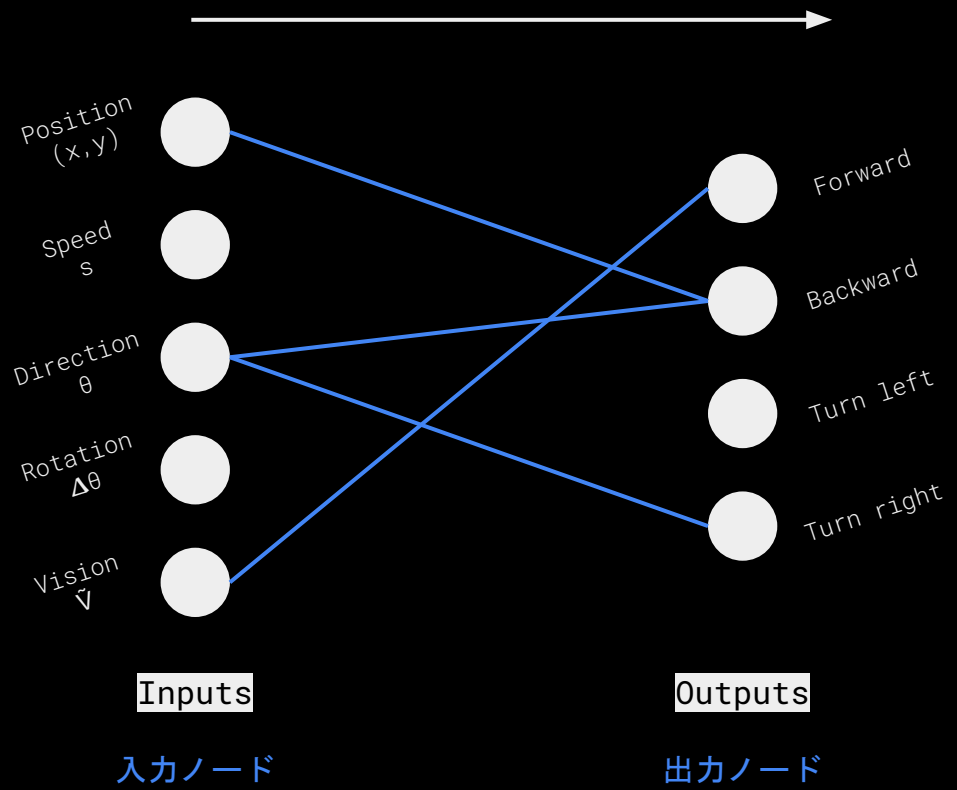


Neural Network Model



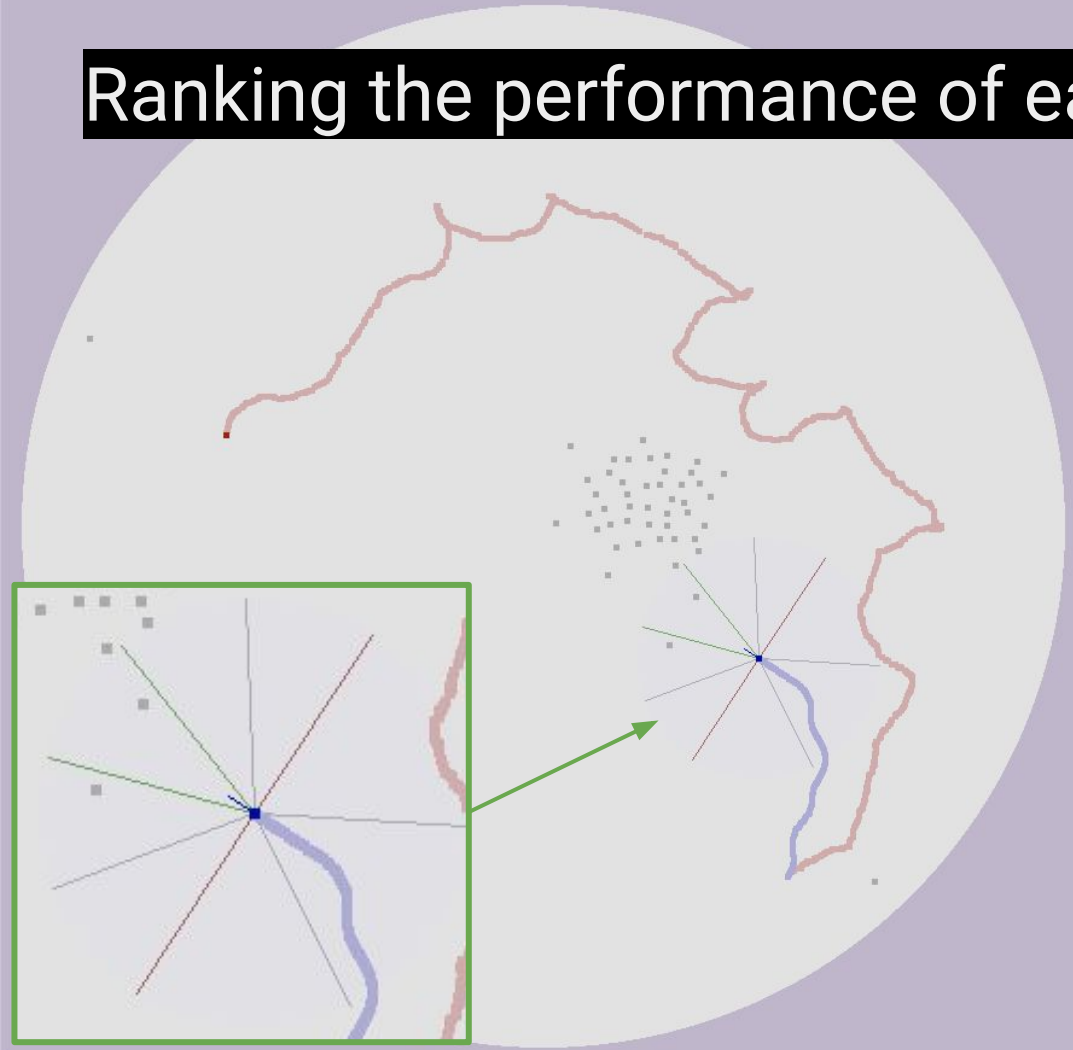
Reproduced behavioural dynamics

Evolving (進化) a neural network



1. Data flows from left to right
   データは左から右へ流れる
2. Initially, a network is randomly connected (+ random weights)
   最初、ネットワークはランダムに接続される
3. Make a population of networks (each randomly generated)
   ネットワークの集団を作る（それぞれがランダムに生成される）
4. Compare the performance of each network in simulation
   シミュレーションで各ネットワークの性能を比較する

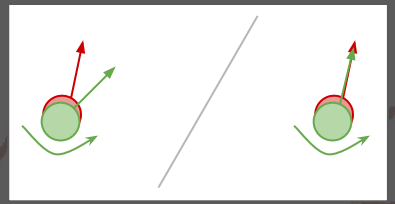
Ranking the performance of each network



1. A network controls a simulated ant
   ネットワークがシミュレートされたアリを制御する
2. Each time step, we compare the behaviour of the real ant and the simulated ant
   各時間ステップで、本物のアリとシミュレートされたアリの行動を比較する
3. After 30 seconds, we can score the network's performance
   30秒後、ネットワークの性能を評価できる
4. Finally, we rank the networks
   最後に、ネットワークをランク付けする

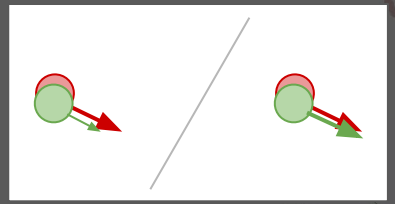
Comparing the dynamics

Angular alignment



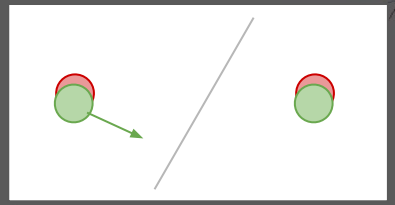
同じ方向

Matching motion



同じ速さ

State transition



同じ状態*

状態遷移というのは、システムが一つの状態から別の状態に変化することを指す。アリの行動をモデル化する際、これは重要な概念である。

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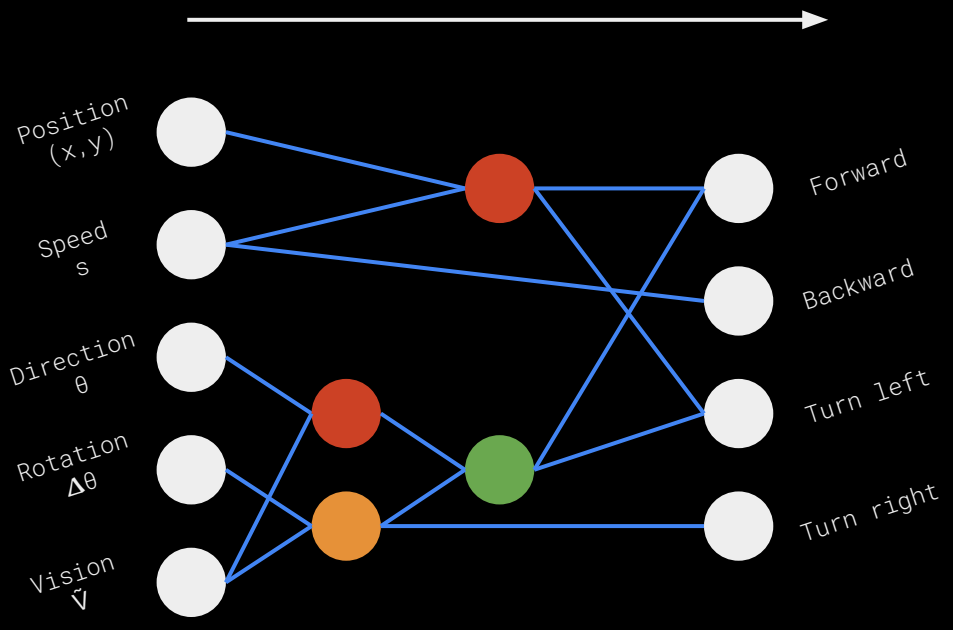
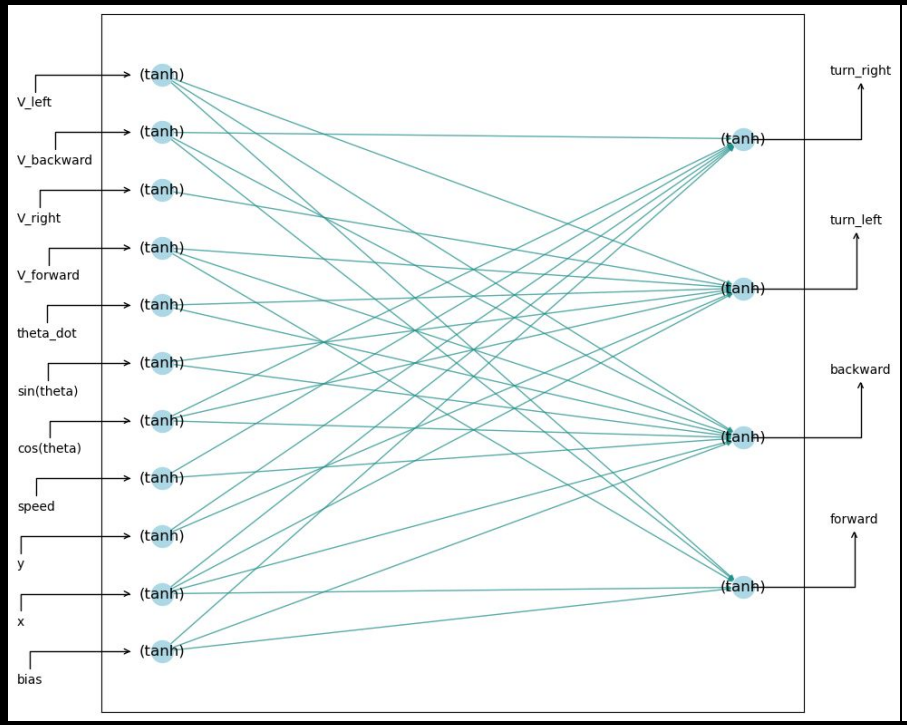
Evolving (進化) a neural network

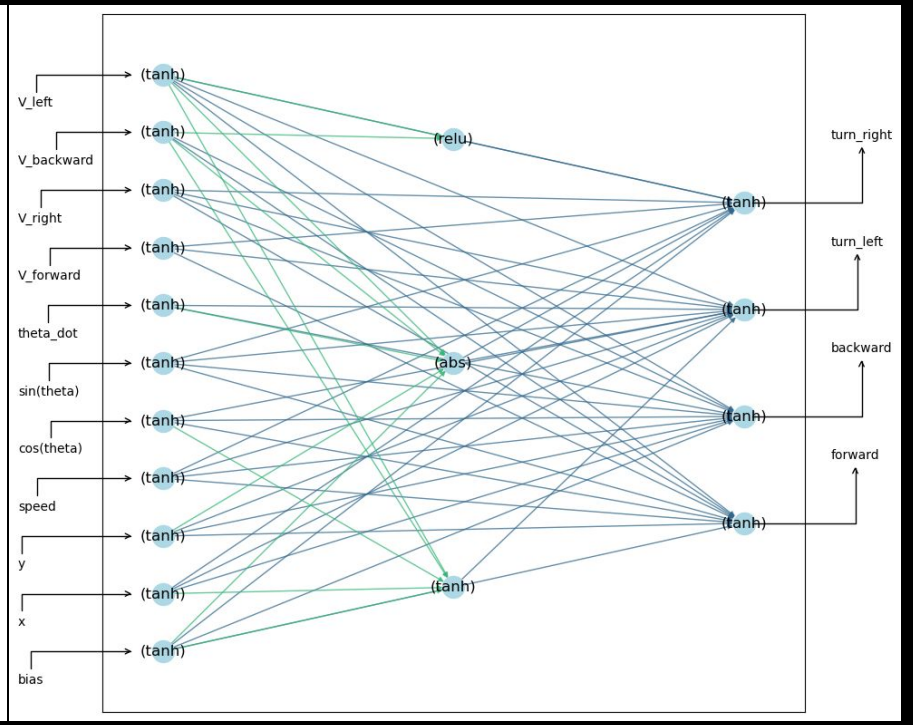


1. Keep the best networks
   最良のネットワークを残す
2. Make copies but apply random mutations
   コピーを作るが、ランダムな突然変異を適用する
3. This can involve adding new connections, or new nodes
   これには新しい接続や新しいノードの追加が含まれることがある
4. The function of a node can also change
   各ノードの数学的関数は変化することがある
5. Repeat this process
   このプロセスを繰り返す

What do the networks look like?

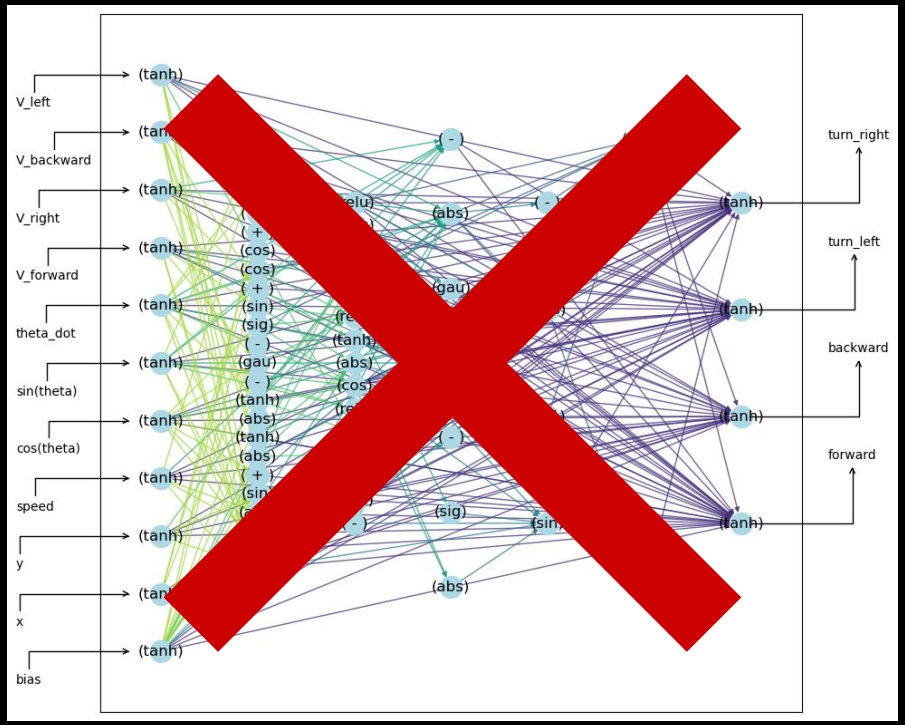


0st Generation (世代)



8th Generation (世代)

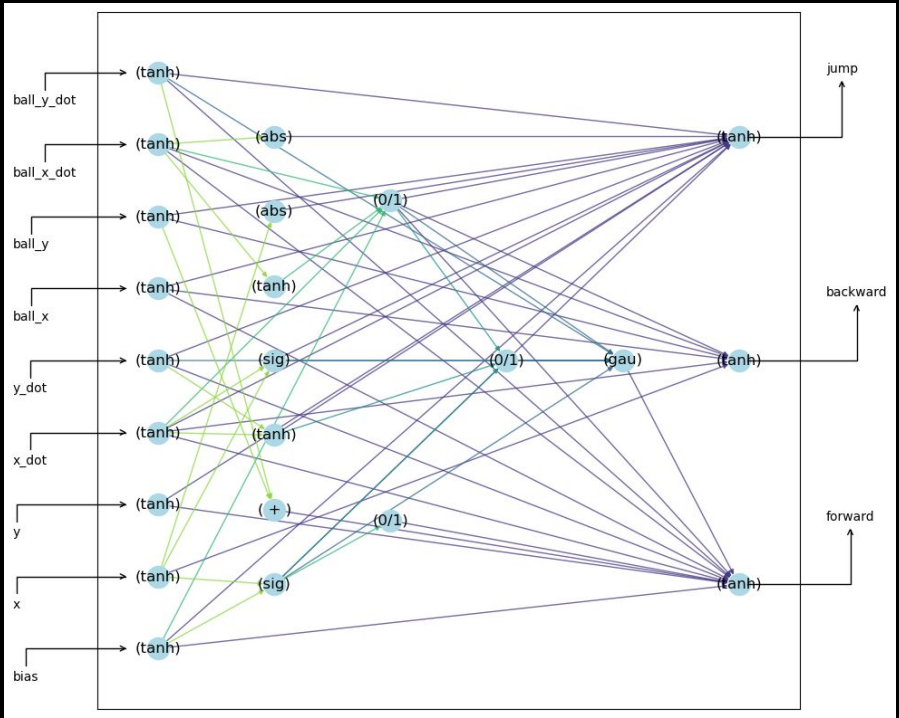
What do the networks look like?



1024th Generation (世代)

- The network has become too complex
  (ニューラル)ネットワークが複雑になりすぎた
- We cannot analyse these networks easily
  これらのネットワークを簡単に分析することはできない
- Such complex networks also do not perform well overall
  このような複雑なネットワークは全体的にも良い性能を示さない

What do the networks look like?



1024th Generation (世代)
(A different example)

- For a different experiment, the resulting networks can be quite simple
  別の実験では、結果として得られるネットワークがかなり単純になることがある
- Well-performing networks can tell us how information is processed
  性能の良いネットワークは情報処理の仕組みを教えてくれる
- The types of functions used can indicate whether the ant's behaviours are random or reactionary
  使用される関数の種類により、アリの行動がランダムか反応的かを示すことができる

What’s missing?

- Pheromones! (フェロモン)
  - The ants mostly use pheromones for aggregation (e.g., clustering together)
    アリは主に集合（例えば、群れを作ること）のためにフェロモンを使用する
  - In the future, we will estimate the presence of pheromones in the model
    今後の研究では、モデル内でのフェロモンの存在を推定しようと考えている
- Time! (時間)
  - We can model short-term behavioural changes
    短期的な行動変化をモデル化できる
  - Changes that occur over many hours are more difficult to model in this way
    何時間もかけて起こる変化は、この方法ではモデル化するのがより難しい

What can we learn from this?

- How reactive are the ants?
  - Does the behaviour seem to be determined by environmental stimuli?

    行動は環境刺激によって決定されているように見えるか？
  - Do the ants possess a complex internal state?

    アリは複雑な内部状態を持っているのか？
- What features of the ants' sensory inputs are important?
  - How do ants estimate local density of the colony?

    アリはコロニーの局所的な密度をどうやって推定するのか？

What are my main research questions?

To build intelligent systems, we have to know:

What conditions are necessary/sufficient for collective intelligence? ←

- X number of cells, ants or bees, people, computers, etc.
- Methods of interaction [話す 見る 伝える 書く]
- How an individual makes decisions *(we learn this by making models)*

From this overarching question, we can then define more precise research questions:

I. In biological systems, how are mechanisms exploited for communication/coordination/cooperation?
II. How is information processed in these systems?
III. What is the minimal information sharing required for collective systems?
    i. Minimum amount of information
    ii. Minimum connectivity

The importance of modelling

- Models (mathematical, computer simulations, etc.) are fundamental in scientific research
  モデルはあらゆる種類の科学の基礎となる
- They are rarely perfect, but they can still be useful
  モデルは完璧であることはめったにないが、それでも役立つことがある
- We can start with a simple model and slowly improve it as we learn more
  簡単なモデルから始めて、理解が深まるにつれて少しずつ改良していける
- Nowadays, more and more scientists are learning how to program, so that they can build models to assist them in their research.
  最近では、研究を助けるモデルを作るために、プログラミングを学ぶ科学者が増えている

Thank you for listening!

Please ask any questions, we will try to answer!

If you have more questions afterwards, please contact me:

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