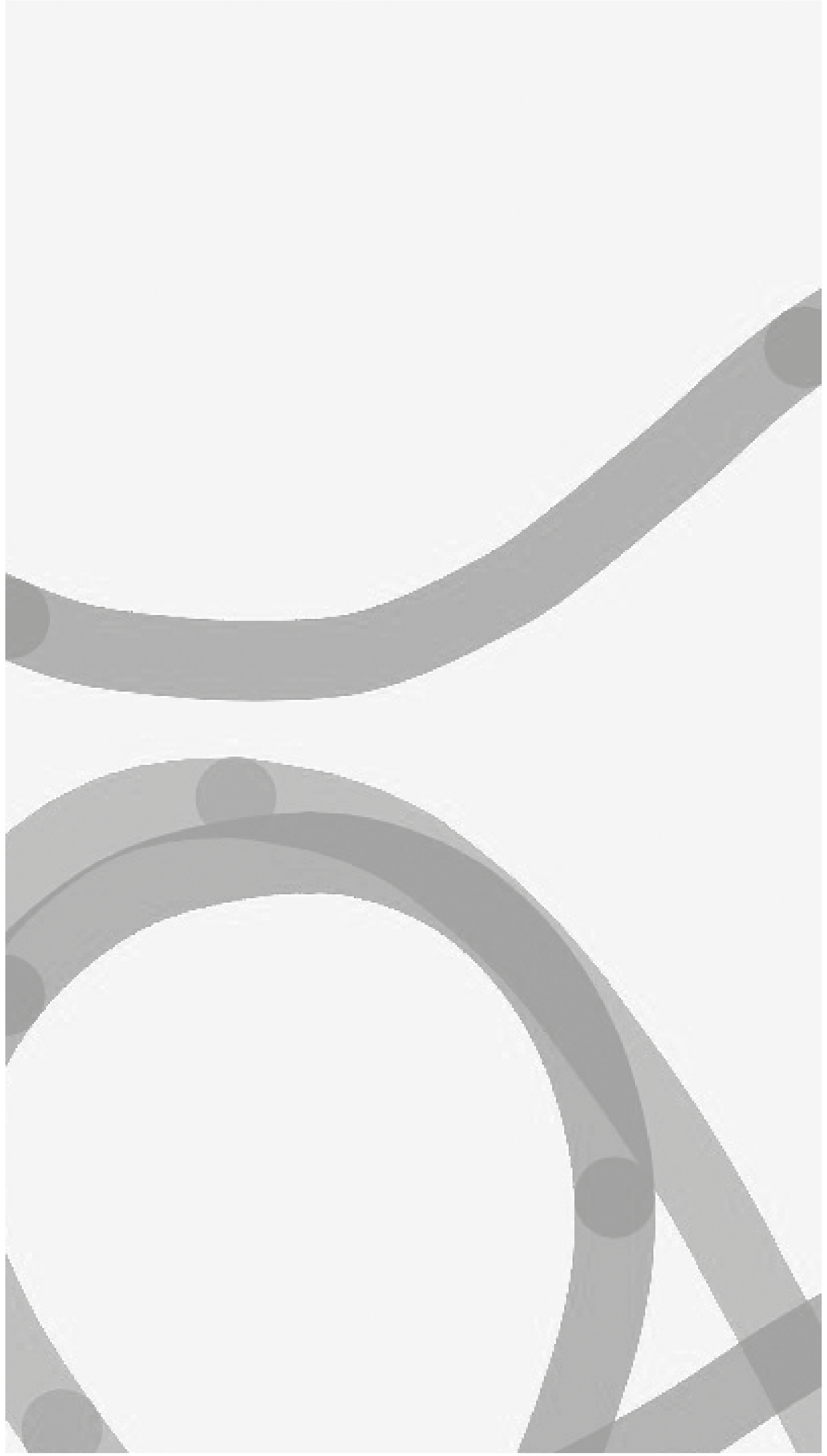

Traces and Frames

Wolfram Liebermeister and/or
Tyyne Claudia Pollmann

Great! Claudia asked me to write something about her art installation, or about the things we discussed while the technical plans developed. What should I write? Whatever you want, she said. I told her I have little time. It can be less than two pages, she said. I said yes, then of course. Very smart. Little time, write a text, topic open. The deadline is apporaching, so I will write something now.

We got to know each oether when Claudia was testing the software for *leave a trace* in our building at the Charité. She told me that my colleagues's movements in the hall, and mine, would be recorded and that the software for reconstructing people's traces still had to be developed. It reminded me of research on people moving in crowds. I had seen movies from an experiment where many people quickly had to leave a stadium. To make them trackable in the movie, they wore hats of different colors. I also thought of the panopticon, which Michel Foucault described in *Discipline and Punish.* People under surveillance, not knowing whether they're actually being watched. They behave like they're supposed to, even if nobody's there to watch them. Here, nobody would be disciplined, let alone punished. The panopticon's place would be taken over by the people. Nobody would be there to watch us, yet everyone would be wtached. Be replaced by a line that slowly fades away, leaving no mark except for some numbers in a data file on the internet. I could try to be the guard. I could download the files and reconstruct the traces. But who drew them, I would't know.

One thing we discussed was how people's movements could be reconstructed as traces in real time. The hall was

the frame to be shown on the screen. Claudia told me that persons would be spotted in the video frames by a software and be represented as 'blobs' in the picture, areas with defined positions and shapes. The center points of these blobs should be connected and turned into smooth curves. This doesn't sound very difficult. But the hall would sometimes be crowded, during conferences aso. What would happen then? Subjects with bright clothes would be hard to detect: their blobs could be missing on some of the video frames, or two blobs could appear instead of one. Nobody was going to wear colorful hats. With many persons roaming in the hall, it might be hard to decide which blobs to connect — then, on the screen, persons might suddenly switch their identities. Or they might disappear or appear out of nothing, like ghosts.

TRACE TO MODEL

Traces, as I would define them, are patterns left behind by some moving object. Scientists study the traces of elementary particles in particle colliders, the migration of sea birds around the globe, and the chemical traces of ants. They reconstruct traces, try to recognise or classify them, and to understand how traces emerge. Some natural processes leave visible traces, other traces can be reconstructed from video, like the movements of fish and birds. Particles in a magnetric field move in circles or spirals — this is because of physical forces and can be descibed by known formulae. Birds flying in flocks move in complicated ways, and scientists try to decipher their laws of motion. Physicists did that research for starlings in Rome. They reconstructed their three-dimensional movements, with thousands of birds in a flock.[1] In the flock there is no leader, all birds respond to each other, and the flock moves like one big creature. Other physicists tried to describe these movements by mathematical models. The models do not describe the aerodynamics of flight, or bird psychology. They are simple and abstract, resembling models that describe the alignment of atom spins in magnetic materials. Actually, a flock of startlings can be described by the same equations as helium atoms in superfluid state, a quantum state close to absolute zero temperature in which helium is liquid but flows without friction.[2] Starling flight, unexpectedly, follows a similar dynamics. When you go to Rome, maybe you see those startlings. They are really impressive. Or search for ‘starling’ and ‘rome’ on YouTube.

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[1] Michele Ballerini, Nicola Cabibbo, Raphael Candelier, Andrea Cavagna, Evaristo Cisbani, Irene Giardina, Alberto Orlandi, Giorgio Parisi, Andrea Procaccini, Massimiliano Viale, Vladimir Zdravkovic, “Empirical investigation of starling flocks: a benchmark study in collective animal behavior”, *Animal Behaviour* 76 (1), 2008, p. 201.

[2] Alessandro Attanasi, Andrea Cavagna, Lorenzo Del Castello, Irene Giardina, Tomas S. Grigera, Asja Jelić, Stefania Melillo, Leonardo Parisi, Oliver Pohl, Edward Shen, Massimiliano Viale, “Information transfer and behavioral inertia in starling flocks”, *Nature Physics* 10, 2014, pp. 691—696.

Traces can tell us about things that happened, but they also guide future movements. Ants leave behind them traces of scents. Other ants follow the scent, add more of it, and thus build a path for more ants to come. Where many people are walking across a lawn, a path will form, and where there is a path, more people may follow. This is an example of self-organised pattern formation, as physicists call it. There is a similar mutual relation between reconstructing traces from images and understanding their physical causes. To reconstruct a trace, it is helpful to know what shapes the traces can show and how they emerge. If we know that particle traces form spirals, we may recognise them, even if the visible spiral is not very clear. The better we understand how traces are formed, the better we can recognise them. And the better we can reconstruct traces, the better we can stud how they form.

The Kalman filter, which Dominik used in his reconstruction algorithm, is a model inspired by physics: we assume a number of persons in the room and describe them as a moving dots. In each moment, each dot has a position and a speed in a certain direction. In each video frame, each dot is then associated with one blob from the video image — maybe simply the closest one — and this blob is used to confirm and adjust the position and speed of the dot. If a blob is missing in a video frame, the dot keeps on moving and can still be confirmed by a blob in the next video frame. New dots are be created as new blobs appear at the side of the hall, and when dots leave the hall, they are deleted from the list. In brief, people create blobs as they are moving, and the dots are attracted by blobs and collect them, like pac-man collects little biscuits in the computer game. Of course, there are many more steps and details to the reconstruction algorithm — Dominik describes them in his text. But the central thing is that there is a model — a representation of reality.

This model, like any other mathematical model, only works in a certain frame. It describes what's happening in the hall and ignores the space around it. It represents persons by dots and keeps no other information from the camera movie. And it frames the movements in a certain way, allowing smooth movements, but no sudden jumps from place to place. And no ghosts. Whenever we use models in science, we know that these models are limited — that the world outside their frame will not be captured. This is why it's important to find the right model.

EFFECT TO CAUSE

Reconstructing the traces for *leave a trace* resembles the tracking of birds, or the tracking of people in a street, filmed by surveillance cameras. In a crowded Charité hall, the blobs might overlap and cluster. If we simply connected blobs that are close to each other, we would not obtain plausible traces, traces that describe how people were walking. Instead of a rule that we're using simply because it is simple, we could also use a model, an idea about the things to be described. Instead of only 'letting the data speak', we start from an idea about reality, how people

generally walk, and use data to make this idea more precise. This procedure — using imprecise data to reconstruct uncertain facts — is common in science. Given our blurred video images or jumping blobs, we can imagine many possible traces of the person that walked across the room. We can consider them as possibilities, but some of them will be very unlikeyly, either becuase people never walk this way, or because the trace is far our blobs. Joining our general knowledge about people walking and our specific knowledge about the camera recordings, we could try to score each possible trace by a probability value.

Why 'probability'? Because formulae from probability theory are used to compute the plausibility values. Bayesian statistics provides methods for computing such values. In fact, it considers a range of possible traces or, more generally, explanatios for our data, and computes a probability for each of them. The so-called Bayesian formulae combines our prior knowledge (in our case, what we know about plausible traces in general) with the so-called likelihood (what the blobs tell us about the trace to be reconstructed). By applying this formula, we obtain for each possible trace the posterior probability. A high posterior probability shows that a trace is plausible. Traces with very low posterior probabilities might be discarded. If we had to pick one best trace, as our guess of the true, original trace, we might pick the one with the highest posterior probability. But we can be almost sure that this reconstruction is not completely correct. What we can do, in fact, and what is common in Bayesian statistics, is to pick many traces with high posterior probability, and see what they have in common. If all these traces resemble each other, we may also assume that they are good reconstructions of the true path of the person observed. If they differ a lot, we can conclude that reconstructing the true trace will be hard.

So how can we implement our prior knowledge about plausible traces? If we had observed many people in the hall and had recorded their true paths, we could expect that a new trace, to be reconstructed from blobs, should resemble these typical traces we know. If we can translate the known traces into a probability distribution, we can use this probability distribution as a prior. With this prior, new reconstructed traces will resemble existing traces, which makes them realistic. But relying too much on prior knowledge can be a problem. If we never saw a person dancing in circles and this now happens for the first time, our algorithm may fail to reconstruct the true trace, because our expectations are strongly biased agsint circles in the trace. Open expectations are important! Otherwise, the reconstructed traces will resemble only the traces we expect and not the ones being performed. This is sometimes seen as a flaw of Bayesian statistics. I think it is not a flaw but a genral problem, which is acknowledged in Bayesian statistics and which other methods tend to sweep under the carpet. This is why, if a reseracher uses Bayesian statistics, the first question will be: how did you choose your prior? In everyday life, we would ask: what did you expect?

For l*eave a trace,* eventually, we did not have to use Bayesian statistics to obtain plausible traces. But this

method is widely applied in biology, for example to recognise the functions of DNA sequences or to reconstruct their changes during evolution.

FRAME TO PLAY

The traces collected by *leave a trace* show that most people just walk across the hall. People would create typical patterns, because of the entry sides to the hall predefining possible start and end points of the paths. During conferences, meetings, or exhibitions, completely new patterns appear. They are caused by objects placed in the hall which then show up as empty spots in a dense network of traces. But every day, people use the installation to draw traces intentionally.

But what happens precisely when such action emerges? Instead of just walking to their laboratory or office, Charité employees would remember that they're being recorded, watch the screen, and start leaving traces deliberately, usng the installation as a drawing tool. Or they would think of an action beforehand, enter the hall, and perform. Performance happens often, as we can tell from the traces, and it's interesting to imagine what happens in this moment. To draw a smooth circle or to write a sentence, one needs to carefully follow one's trace on the screen to constantly adapt one's movement. It's like moving your arm: there's no predefined programme, we constantly move, sense, and adust. Then we start playing, drawing, watch the line we drew, and see where it leads us. Improvise. Or people draw pictures together. They may run around, dance or chase each other, or follow each other's traces.

Uri Alon, an Israeli systems biologist, studied the 'mirror game', in which two players improvise motions.[3] A player can smoothly move a handle and see how the other player responds with her movements. There are three simple rules: "Imitate each other, create synchronised and interesting motions, and enjoy playing together." As people play, common motions begin to emerge. Sometimes one player leads, the other one follows. Or they are in tune and do their movements together. The improvisation starts to create unspoken rules, which appear and disappear. They emerge like waves in a flock that emerge from movements of birds, easy to follow but hard to pin down. But the recordings from the mirror game experiments show that players in tune follow each other's movements more precisely than a player who simply follows the a leader. In playing, there is not just communication — there is always also the message "this is play", as Gregory Bateson put it. In the mirror game, as new games emerge from improvisation, players tell each other: "I'm still playing, and we can invent new games."[4] Play and game are so closely entangled —

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[3] Lior Noy, Erez Dekel, Uri Alon, "The mirror game as a paradigm for studying the dynamics of two people improvising motion together", *Proc. Natl. Acad. Sci. U.S.A.* 101 (52), 2011, p. 20947.

[4] Gregory Bateson, "The message 'this is play'", in B. Schaffner (ed.), *Group Processes: Transactions of the Second Conference,* pp. 145—242 New York 1956, pp. 145—242.

maybe it's no surprise that Germans use the same word for both of them.

leave a trace offers a mirror game for any number of players. People can see each others' traces and the traces they're drewing, and can respond to them. Like a mirror, the installation reflects people's movements, and like an experimental set-up, it records them. Just like a mirror, it can be ignored. But its presence in the room offers a possible change of viewpoint, possibilities to act and react. To see and decide. The installation provides a frame for play. People passing suddenly realise that they're being recorded. They start checking their traces, check the way they're walking. For the camera. For themselves. Every step is recorded. The traces remain, slowly fading out, and invite others to respond to past actions. Some may not want to be filmed, avoid walking through the hall, and use the hallways around it. Leaving the frame of the hall, but responding to being traced. Others simply walk across the hall, in the frame. They will be traced, but the camera doesn't affect them.

GAME TO SCIENCE

Scientists do not only study how people play games. They also use games to solve problems, even hard ones. Protein folding is the process by which proteins get their shapes, a process that makes them become functional. Predicting the shape of protein can be very difficult, even with the fastest computers. But scientist developed an online game called foldit that lets players try out and improve foldings of actual proteins. This really works: foldit players managed to find protein crystal structures that scientists couldn't decipher for many years, and to redesign proteins to create more powerful enzymes. It may be true that it's "the human brain's three-dimensional pattern matching and spatial reasoning abilities" that enable players to solve these problems, as wikipedia authors put it.[5] But I think that it's also the very process, the interaction with the game, the fact that players can improvise, try out solutions, and are guided by pictures of what they created so far. And unlike any algorithm, players are conscious of what they are doing and can reflect their strategies. They have collected recipes for protein folding that they invented while playing. They shared and modified thousands of these recipes and created a new efficient algorithm for protein folding that was not known at that time.[6] You can play Foldit, too, and even contribute to medical research. On https://fold.it/ there are open challenges in whcih players are asked to find new protein foldings that may help find cures for diseases.

A student team at the Centre de Recherches Interdisciplinaires in Paris (cri-paris.org) is developing another game, Hero.Coli (herocoli.com). Here the player steers a little bacterial cell to collect genetic elements, pieces of DNA, and to connect them to genetic circuits that give the cell new abilities. It works like in a Pokemon game, but with realistic simulations of cellular pathways in the background. If such a game had an interface to the Systems Biology Markup Language (sbml.org), it would allow users to plug into their cells one of the thousands of simulation models that have been developed by scientists. Players could download such models and plug them into the game to add new biochemical pathways to their simulated cells. They could start sharing pathway models with their friends as if they were magic swords. The game would become a general simulator for cells. Like in foldit, players could invent new ways of modifying a living cell: the disctinction between playing and research completely blurred.

The step from playing with models to playing with living cells is not large, at least in synthetic biology. Synthetic biology is a form of genetic engineering in which cells are modifed by introducing new genetic elements into reality. A central event is the yearly iGEM challenge (igem.org), in which student teams present new ways in which they modifeid cells for specific purposes. New genetic parts (called 'biobricks', like Lego bricks) can later be used by other teams. The event is organised as a competition to make it feel like a game. From year to year there are more biobricks that can be combined. New ideas are emerging, and they are driven by the newly emerging materials. In a way, every contribution to the contest creates new traces: new biobricks or new ideas that will be used in other projects, and so the projects themselves form a network of traces. I am fascinated

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[5] https://en.wikipedia.org/wiki/Foldit

[6] Firas Khatib, Seth Cooper, Michael D. Tyka, Kefan Xu, Ilya Makedon, Zoran Popović, David Baker and Foldit Players, "Algorithm discovery by protein folding game players", *Proc. Natl. Acad. Sci. U.S.A.* 108 (47), 2011 p. 18949.

and worried about this. Gaming is so attractive. And taking part in a game, one can easily lose the sense of what is important or useful for others. When the game is over.

This is it. I have written more than two pages, I need to shorten. I will leave some of the typos as a trace to the first attempt. But maybe I'm lying, maybe I have rewritten the text many times, and added all typos on prupose. You will not know what I fixed, or left on purpose, and what escaped my attention. (CLAUDIA, CAN YOU PLEASE MAKE SURE MY TYPOS WILL STAY THE WAY THEY ARE? THANK YOU!). But then, we could also leave our comments unfixed. But maybe this text will still change after I'm done, and before you're reading it now? Claudia could add her thoughts and erase mine. Shorten. She could add new typos, maybe in tis sentence. But again, you will not know what actuially happened, what she wrote and what I wrote. Or did I just invent this cooperation? (CLAUDIA, IS THIS TOO MUCH?) Traces are complicated things, one never knows how they should bve read. (CLAUDIA, YOU CAN MAKE IT SOUND LIKE YOU WROTE THE ENTIRE TEXT, AND YOU JUST INVENTED ME.)

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