From Descartes to Turing: the Computational Content of Supervenience
Outline:

- Descartes, dualism and the problem of mental causation
  - Supervenience as workspace for making mind-body connections ... and emergence as a tool
  - The rise and fall of the British emergentists
  - Clarifying emergence - synergetics, Turing, definability
  - Fragmentation, coherence, and Descartes revisited
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In general - Descartes aims to explain in terms of strictly mechanical principles and mathematical models.

BUT - declares the essential non-physicality of the mind.

Substance Dualism

I [am] a substance the whole essence or nature of which is to think, and for its existence there is no need of any place, nor does it depend on any material thing; so that this me, that is to say, the soul by which I am what I am, is entirely distinct from body ...

- Discourse on Method, Part IV, Paris, 1637
The Problem of Mental Causation

- How can mentality have a causal role in a world that is fundamentally physical?

- And what about ‘overdetermination’ - the problem of phenomena having both mental and physical causes?

... the problem of mental causation is solvable only if mentality is physically reducible; however, phenomenal consciousness resists physical reduction, putting its causal efficacy in peril.

-Jaegwon Kim: *Physicalism, or Something Near Enough*, Princeton, 2005
How do we characterise the link between mind and physical world? In a way that respects the complexities involved?

- Reductive physicalism or nonreductive physicalism

- Anomalous monism (Donald Davidson, 1970)

- Epiphenomenalism (T.H. Huxley 1874, ...), functionalism

- Emergentism (J.S. Mill, C.D. Broad, C. Lloyd Morgan, Samuel Alexander...)
Supervenience as Workspace

Supervenience ‘represents the idea that mentality is at bottom physically based, and that there is no free-floating mentality unanchored in the physical nature of objects and events in which it is manifested’


“A set of properties A supervenes upon another set B just in case no two things can differ with respect to A-properties without also differing with respect to their B-properties.”

Stanford Encyclopedia of Philosophy
If mental supervenes on physical - how do the complexities of the physical world match those of the mental - and, potentially, of the mirroring process?
Galileo and Newton onwards - overarching aim of science became the extraction of the mechanical content of the world - a ‘clockwork universe’
"Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situations of the beings who compose it - an intelligence sufficiently vast to submit these data to analysis - it would embrace in the same formula the movements of the greatest bodies and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes."

from P. S. de Laplace [1819], “Essai philosophique sur les probabilités”
No Ghost in Turing’s Machine

- 1936 - Turing’s machines appear
- Provide a model of computable natural processes within a wide range of contexts

Gilbert Ryle (1900-1976)
No Ghost in Turing’s Machine

- 1936 - Turing’s machines appear
- Provide a model of computable natural processes within a wide range of contexts

But - techniques for presenting machines give the **Universal Turing machine** - and **incomputable objects**

A familiar picture:

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0 0 1 1 0 0 0 . . .. . .
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reading head which is in internal state \( q \) and obeys Turing program \( P \).

Tape, infinitely extendable in each direction.
Natural phenomena as discipline problem

- Successful reduction of “natural” examples to the Turing model - e.g. quantum computation (David Deutsch)
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- Successful reduction of “natural” examples to the Turing model - e.g. quantum computation (David Deutsch 1985)

I am sure we will have [conscious computers], I expect they will be purely classical, and I expect that it will be a long time in the future. Significant advances in our philosophical understanding of what consciousness is, will be needed.

Question and Answers with David Deutsch, on New.Scientist.com News Service, December, 2006
Natural phenomena as discipline problem

The great success of modern computers as all-purpose algorithm-executing engines embodying Turing's universal computer in physical form, makes it extremely plausible that the abstract theory of computability gives the correct answer to the question ‘What is a computation?’ and, by itself, makes the existence of any more general form of computation extremely doubtful.

Martin Davis [2004], The myth of hypercomputation. In Alan Turing: Life and legacy of a great thinker (C. Teuscher, ed.), Springer-Verlag
But back in the real world ...

- Persistence of problems of predictability - quantum uncertainty, emergent phenomena, chaos and strange attractors, relativity and singularities (black holes)

- Renewed interest in analog and hybrid computing machines leading to: “... the classical Turing paradigm may no longer be fully appropriate to capture all features of present-day computing.”

Co-operative phenomena ...

1970 - Georg Kreisel proposes a collision problem related to the 3-body problem, which might result in "an analog computation of a non-recursive function"
Mathematical analogues of chaos

- Growth of Chaos theory, generation of informational complexity via very simple rules, accompanied by the emergence of new regularities - e.g. Robert Shaw’s dripping tap [1984]

- Link between structures in nature, and mathematical objects, such as the Mandelbrot and Julia sets

- Penrose, Smale - computability of Mandelbrot, Julia sets?
Now we witnessed ... a certain extraordinarily complicated looking set, namely the Mandelbrot set. Although the rules which provide its definition are surprisingly simple, the set itself exhibits an endless variety of highly elaborate structures.

Roger Penrose
in “The Emperor’s New mind”, Oxford Univ. Press, 1994

A mathematical example of emergent structure
Emergence occurs everywhere ...
... perhaps even in getting intelligent machines ...

"I used to think we’d do it by engineering. Now I believe we’ll evolve them. We’re likely to make thinking machines before we understand how the mind works, which is kind of backwards."

- Daniel Hillis, Chief Technology Officer of Applied Minds, Inc. (and ex-Vice President, Research and Development at Walt Disney Imagineering), April 2001
... the characteristic behaviour of the whole ... could not, even in theory, be deduced from the most complete knowledge of the behaviour of its components ... This ... is what I understand by the ‘Theory of Emergence’. I cannot give a conclusive example of it, since it is a matter of controversy whether it actually applies to anything ... I will merely remark that, so far as I know at present, the characteristic behaviour of Common Salt cannot be deduced from the most complete knowledge of the properties of Sodium in isolation; or of Chlorine in isolation; or of other compounds of Sodium, ..."

“... the mental properties of those events which do have mental properties are completely determined by the material properties which these events also have ... it is certainly not ... a form of Reductive Materialism; it is a form of the theory ... of Emergent Materialism.”


Emergence is often invoked in an almost mystical sense regarding the capabilities of behavior-based systems. Emergent behavior implies a holistic capability where the sum is considerably greater than its parts. It is true that what occurs in a behavior-based system is often a surprise to the system's designer, but does the surprise come because of a shortcoming of the analysis of the constituent behavioral building blocks and their coordination, or because of something else?

A Test for Emergence

1) Design: The system has been constructed by the designer, by describing local elementary interactions between components (e.g., artificial creatures and elements of the environment) in a language $L_1$.

2) Observation: The observer is fully aware of the design, but describes global behaviors and properties of the running system, over a period of time, using a language $L_2$.

3) Surprise: The language of design $L_1$ and the language of observation $L_2$ are distinct, and the causal link between the elementary interactions programmed in $L_1$ and the behaviors observed in $L_2$ is non-obvious to the observer - who therefore experiences surprise. In other words, there is a cognitive dissonance between the observer's mental image of the system's design stated in $L_1$ and his contemporaneous observation of the system's behavior stated in $L_2$.

Emergence of patterns in Nature

1950s - Alan Turing proposes a simple reaction-diffusion system describing chemical reactions and diffusion to account for morphogenesis, i.e., the development of form and shape in biological systems.

See http://www.swintons.net/jonathan/turing.htm
Chaos, Order and Self-Organisation

- **SYNERGETICS** - the study of the origins and evolution of macroscopic patterns and spacio-temporal structures in interactive systems

- Emphasis on mapping out self-organisational processes in science and the humanities - e.g. autopoiesis

- Mathematical modelling of nonlinear and irreversible processes, dissipative structures ...

Descriptions and Emergent Structure

- Notice - It is often possible to get descriptions of emergent properties in terms of the elementary actions.

- E.g., this is what Turing did for the role of Fibonacci numbers in relation to the sunflower etc.

- In mathematics, it is well-known that complicated descriptions may take us beyond what is computable.

- A potential source of surprise in emergence ...
Descriptions and Emergent Structure ...

- **Intuition** - entities exist because of, and according to, mathematical laws. In the words of Leibniz [1714] -

- ‘The Monadology’, sections 31, 32: “... there can be found no fact that is true or existent, or any true proposition, without there being a sufficient reason for its being so and not otherwise, although we cannot know these reasons in most cases.”
... and definability
the key concept

- So natural phenomena not only generate descriptions, but arise and derive form from them . . .

- ... so connecting with a useful abstraction - the concept of mathematical definability ...

- ... formalising describability in a mathematical structure

- Giving precision to our experience of emergence as a potentially non-algorithmic determinant of events
I believe the following aspects of evolution to be true, without knowing how to turn them into (respectable) research topics.

**Important steps in evolution are robust.** Multicellularity evolved at least ten times. There are several independent origins of eusociality. There were a number of lineages leading from primates to humans. If our ancestors had not evolved language, somebody else would have.
Supervenience ‘represents the idea that mentality is at bottom physically based, and that there is no free-floating mentality unanchored in the physical nature of objects and events in which it is manifested’


Look for a clarified notion of emergence for pinning down the nature of supervenience - and so, of intelligence

☐ The aim - physicalism and dualism reconciled ...
Achieve a non-reductive physicalism, delivering -

- Mind-body supervenience
- The physical irreducibility of the mental - including consciousness, qualia
- And the causal efficaciousness of the mental
- With definability removing conflict between ‘vertical’ determination and ‘horizontal’ causation

Post-Cartesian expectations ...
Emergence and Mathematical Intuition

“At first Poincaré attacked [a problem] vainly for a fortnight, attempting to prove there could not be any such function ... [quoting Poincaré]:

‘Having reached Coutances, we entered an omnibus to go some place or other. At the moment when I put my foot on the step, the idea came to me, without anything in my former thoughts seeming to have paved the way for it ... I did not verify the idea ... I went on with a conversation already commenced, but I felt a perfect certainty. On my return to Caen, for conscience sake, I verified the result at my leisure.’

from Jacques Hadamard [1945], “The Psychology of Invention in the Mathematical Field”, Princeton Univ. Press
‘Then I turned my attention to the study of some arithmetical questions apparently without much success ... Disgusted with my failure, I went to spend a few days at the seaside and thought of something else. One morning, walking on the bluff, the idea came to me, with just the same characteristics of brevity, suddenness and immediate certainty, that the arithmetic transformations of indefinite ternary quadratic forms were identical with those of non-Euclidian geometry.’

from Jacques Hadamard [1945], "The Psychology of Invention in the Mathematical Field", Princeton Univ. Press
Thoughts as Emergent Phenomena

- Need to bridge the gap between ‘emergent’ higher mental functionality and ... what algorithmic ‘design’?
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Difficult - Rodney Brooks [Nature, 2001]: “neither AI nor Alife has produced artifacts that could be confused with a living organism for more than an instant.”
Intelligent Thoughts as Emergent Phenomena

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So does emergence explain what we observe ... is that all there is?
There is a reasonable chance that connectionist models will lead to the development of new somewhat-general-purpose self-programming, massively parallel analog computers, and a new theory of analog parallel computation: they may possibly even challenge the strong construal of Church's Thesis as the claim that the class of well-defined computations is exhausted by those of Turing machines.

Connectionist Models of Computation?

- These have come a long way since Turing's [1948] discussion of 'unorganised machines', and McCulloch and Pitts [1943] early paper on neural nets.

- But for Steven Pinker “... neural networks alone cannot do the job”.
Connectionist Models of Computation?

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- But for Steven Pinker “… neural networks alone cannot do the job”.

And focussing on our elusive higher functionality, he points to a “kind of mental fecundity called recursion” …
Emergent mental images re-used

We humans can take an entire proposition and give it a role in some larger proposition. Then we can take the larger proposition and embed it in a still-larger one. Not only did the baby eat the slug, but the father saw the baby eat the slug, and I wonder whether the father saw the baby eat the slug, the father knows that I wonder whether he saw the baby eat the slug, and I can guess that the father knows that I wonder whether he saw the baby eat the slug, and so on.

Steven Pinker,
Definability as a Key to Representation

“As the brain forms images of an object - such as a face, a melody, a toothache, the memory of an event - and as the images of the object affect the state of the organism, yet another level of brain structure creates a swift nonverbal account of the events that are taking place in the varied brain regions activated as a consequence of the object-organism interaction. The mapping of the object-related consequences occurs in first-order neural maps representing the proto-self and object; the account of the causal relationship between object and organism can only be captured in second-order neural maps. ... one might say that the swift, second-order nonverbal account narrates a story: that of the organism caught in the act of representing its own changing state as it goes about representing something else.”

- Antonio Damasio [1999], The Feeling Of What Happens, p.170
Definability in What Structure?

- In modelling the physical universe -

... causality itself is fundamental

The Turing model extended

- 1939 - Turing’s oracle Turing machines
- Provide a model of algorithmic content of structures, based on p.c. functionals over the reals

A familiar picture:
0 0 1 1 0 0 0 ... reading head which is in internal state $q$ and obeys Turing program $P$

tape, infinitely extendable in each direction

... 0 0 1 1 0 0 0 ...
The Turing model extended

- 1939 - Turing's oracle Turing machines
- Provide a model of algorithmic content of structures, based on p.c. functionals over the reals
- 1944 - Post defines the degrees of unsolvability as a classification of reals in terms of their relative computability
- Giving a landscape with a rich structure
The Turing landscape, causality and emergence ...

- Can describe global relations in terms of local structure ...
- ... so capturing the emergence of large-scale formations
- Mathematically - formalise as definability over structure based on Turing functionals?
- More generally - as Invariance under automorphisms
Hartley Rogers’ programme ...

Fundamental problem: Characterise the Turing invariant relations
Hartley Rogers’ programme ...

Fundamental problem: Characterise the Turing invariant relations

- Intuition: These are key to pinning down how basic laws and entities emerge as mathematical constraints on causal structure

- Notice: The richness of Turing structure discovered so far becomes the raw material for a multitude of non-trivially definable relations
Mental Causation Revisited

- How can mentality have a causal role in a world that is fundamentally physical?
- And what about ‘overdetermination’ - the problem of phenomena having both mental and physical causes?

... the problem of mental causation is solvable only if mentality is physically reducible; however, phenomenal consciousness resists physical reduction, putting its causal efficacy in peril.

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Mental Causation Revisited

Causality - a misleading concept in this context

- Recognisable ‘causality’ occurs at different levels of the model, connected by relative definability ...

- ... but in the form of relations with identifiable algorithmic content, this content at higher levels being emergent

- The diverse levels form a unity, with the ‘causal’ structure observed at one level reflected at other levels - with the possibility of non-algorithmic ‘feedback’ between levels
Downward Causation

The “levels” involved are levels of organisation and integration, and the downward influence means that the behavior of “lower” levels - that is, of the components of which the “higher-level” structure consists - is different than it would otherwise be, because of the influence of the new property that emerges in consequence of the higher-level organization.

Summary - science and mathematics can play an important part in clarifying philosophical problems - and the notion of definability is a specially useful tool in a wide range of contexts.
Thank you!