EMERGENCE AND REDUCTION: GO HAND IN HAND?

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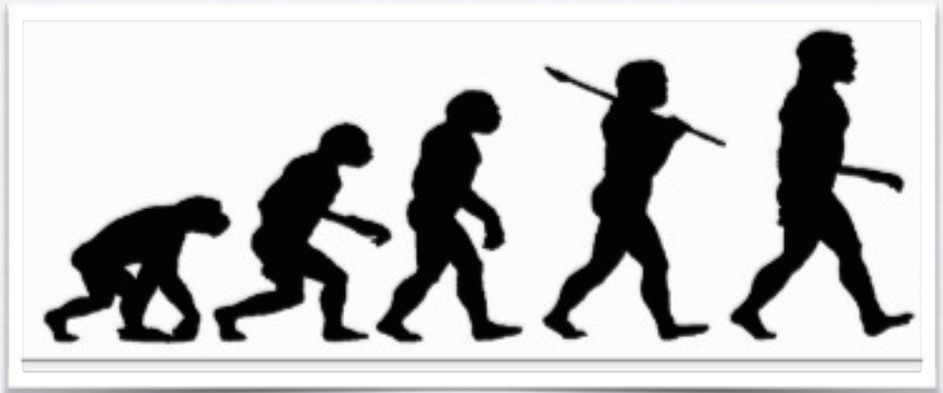
THE EVOLVING RELATIONSHIP BETWEEN REDUCTION AND EMERGENCE

- At first, emergence was defined to be the failure of reduction.

- Then emergence was shown to be compatible with reduction (Butterfield 2011, and inter alia Crowther 2015 & J. Wilson 2015).

- In this talk, I want to argue that (at least in some cases) reduction and emergence might go hand in hand.



Emergence: novel and robust behaviour wrt to some comparison class (Butterfield, 2011).

Reduction: a theory T_t is reduced to T_b if the equations/quantities/variables of T_t have been constructed from the equations/quantities/ variables of T_b

TALK OUTLINE

1. **The statistical mechanical case study:** show how the irreversible equations of SM can be constructed from (reduced to) the underlying microdynamics, and why the resultant time-asymmetry is emergent a la Butterfield.

2. **Why argue that a reduced theory might describe emergent entities?**

3. **How a reduced theory fulfils the novelty and robustness criteria - and so describes emergent entities.**

THE SM CASE STUDY

- Whilst the underlying microdynamics of CM or QM are time-reversal invariant, the processes described by statistical mechanics are not: they are irreversible.

- Example: the spontaneous approach to equilibrium as described by the Boltzmann equation.

A TRADITIONAL PUZZLE

"How can this irreversibility of macroprocesses be reconciled with the reversibility of microprocesses? It is this paradox which the physicist has to solve when he wishes to account for the direction of thermodynamic processes."

– Reichenbach (1991, p.109).

- The Zwanzig-Zeh-Wallace (ZZW) framework shows how the irreversible equations can be *constructed* from the underlying microdynamics.

- It uses *coarse-graining*, which has been heavily criticised as 'subjective' - elsewhere I defend coarse-graining.

- This is a case of inter-theoretic reduction.

1. THE ZZW FRAMEWORK

stage 1: move to the ensemble variant: ρ evolves under $\boldsymbol{L}$.

stage 2: introduce generalised coarse-graining projections, $\boldsymbol{P}$; & thus we introduce 'relevant' DOF.

$$\boldsymbol{P\rho=\rho_r\,,\ (I-P)\rho=\rho_{ir}\,,\ where\ \rho=\rho_r+\rho_{ir}}$$

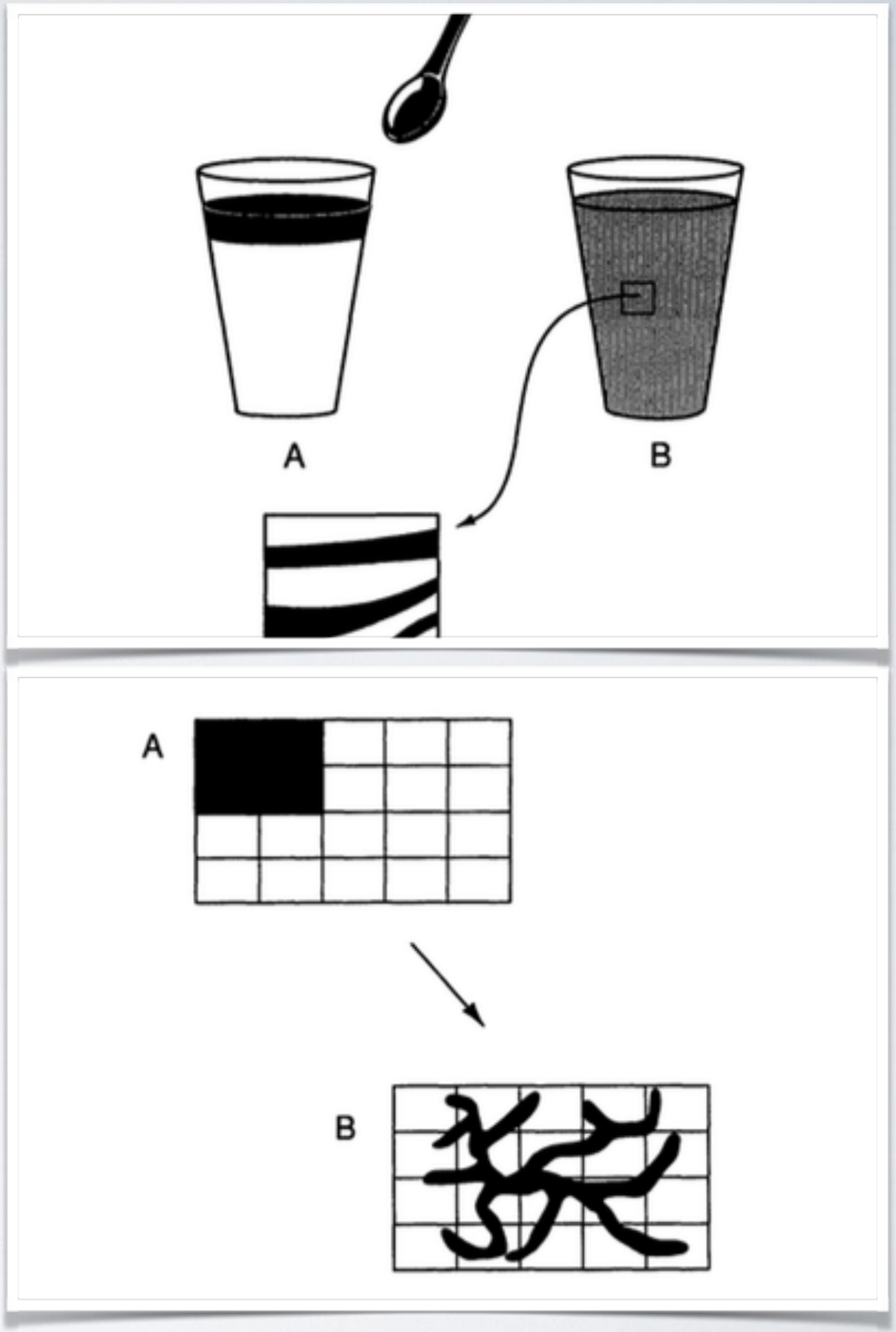
A GIBBSIAN COARSE-GRAINING

- Averaging **ρ** over volume elements ΔV gives ρ_r

- **ρ** fibrillates across the available phase space.

- ρ_r spreads smoothly.

- Another example: throwing away two or more particle correlations.



Images from Sklar (1993)

THE ZZW FRAMEWORK

stage 3: find an autonomous equation, the C+ dynamics, for ρ_r.

$$f(\rho_r) \text{ rather than } f(\rho_r, \rho_{ir}, t)$$

Two assumptions are required:

A. The initial state assumption

B. The Markovian approximation

$$\frac{\partial \rho_r(t)}{\partial t} = \hat{F}\rho_{ir}(t_0) + \int_{t_0}^{t} dt' G(\hat{t'})\rho_r(t-t')$$

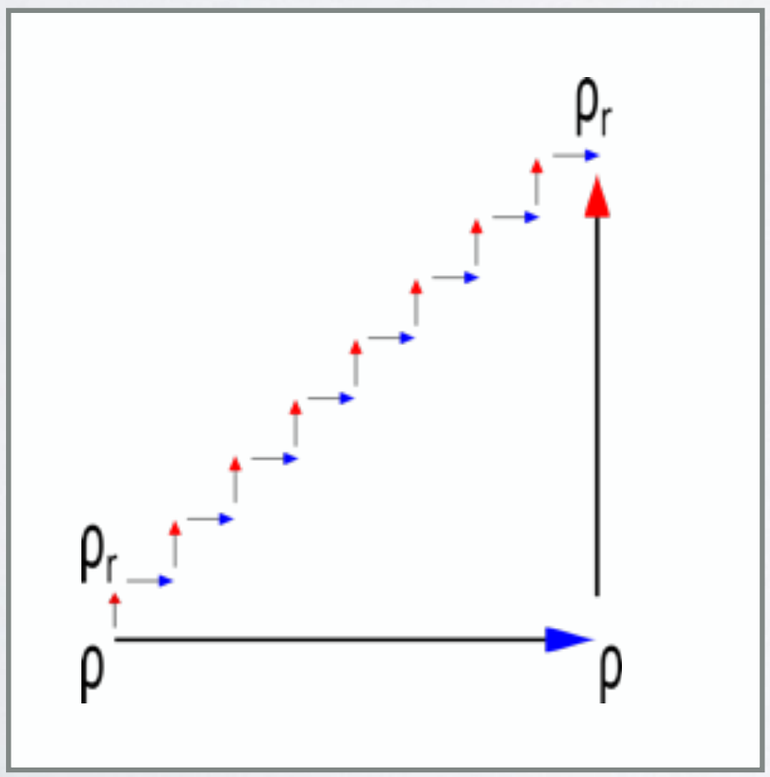
where $\hat{F} := PLe^{-it(1-P)L}$ and $G(\hat{t'}) := PLe^{it'(1-P)L}(1-P)L$

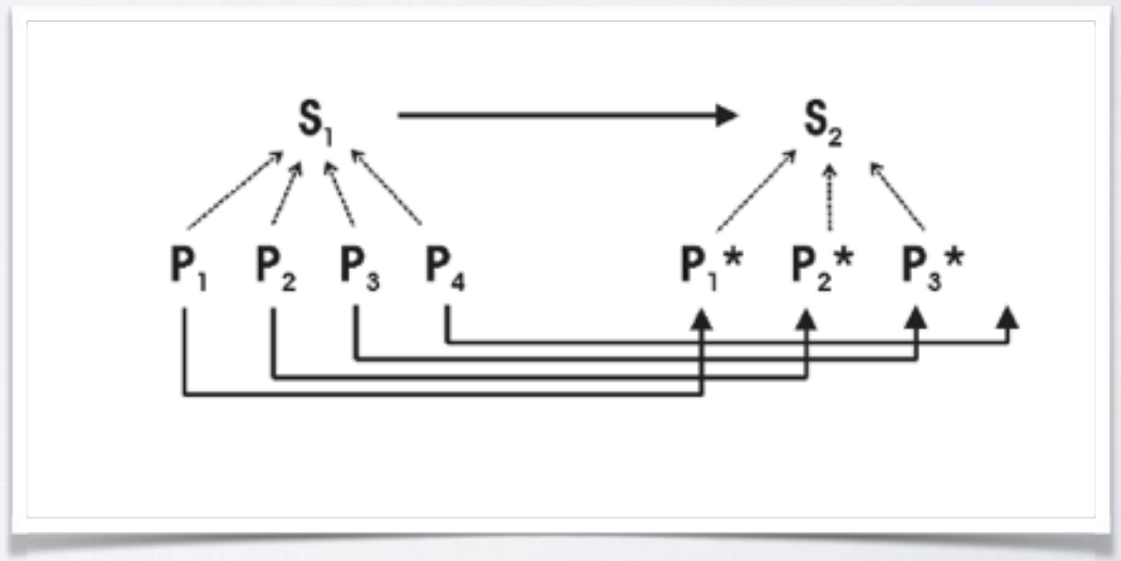
Final result: an irreversible equation - entropy increases.

$$\frac{dS[\rho_r]}{dt} \geq 0.$$

WHY DOES THE ZZW RECIPE WORK?

- A 'meshing' dynamics (Butterfield 2012, List 2016):
  - If the two assumptions are fulfilled then coarse-graining at every time-step (the C+ dynamics) gives the same distribution ρ_r at t as coarse-graining once at the end: **forwards-compatible** (Wallace, 2011).





- "Do the procedures for deriving kinetic equations and the approach to equilibrium really generate *fundamentally* time-asymmetric results?"

  - Sklar (1993, p. 217).

☛ No, the asymmetry is emergent.

- *Contra:* "Irreversibility is either true on all levels or on none: it cannot emerge as if out of nothing, on going from one level to another"

  - Prigogine and Stengers (1984, p. 285).

THE EMERGENT TIME-ASYMMETRY

Butterfield's criterion of emergence: **novel** and **robust** behaviour wrt to some comparison class.

- **Novelty**: the asymmetry is novel wrt to underlying microdynamics time-symmetry.

- **Robust**: the asymmetry is robust wrt the number of coarse-grainings *P*.

The coarse-grained asymmetry is **robust.**

$$\begin{array}{ccccccc}
\rho_r(t_0) & & \rho_r(t_1) & & & & \rho_r(t_n) \\
\uparrow \hat{P} & & \uparrow \hat{P} & & & & \uparrow \hat{P} \\
\rho(t_0) & \xrightarrow{U(t)} & \rho(t_1) & \xrightarrow{U(t)} & \rho(t_2)\ldots & \xrightarrow{U(t)} & \rho(t_n)
\end{array}$$

Route 1: to find ρ_r at any t, evolve ρ under U until t then coarse-grain

$$\rho_r(t_0) \xrightarrow{C^+(t)} \rho_r(t_1) \xrightarrow{C^+(t)} \ldots \xrightarrow{C^+(t)} \rho_r(t_n)$$

Route 2: to find ρ_r at any t, evolve ρ_r under the coarse-grained constructed dynamics

- So here we have a case of inter-theoretic reduction going hand in hand with emergence.

- *Unsurprising!* The definition of emergence used here has been explicitly shown to be compatible with reduction.

- But my aim: this isn't just a special case… More generally, reduction goes hand in hand with emergence.

- So even if the 'special sciences' are shown to be reduced, they could still be emergent.

2. WHY ASK THE QUESTION?
(DOES A REDUCED THEORY DESCRIBE EMERGENT ENTITIES)

- Reducing T_t to T_b *vindicates* T_t - it explains why T_t was so successful.
- Reduction…leads to elimination? (cf. Kim, 1998, 1999)
- The properties/quantities discussed by T_t *really were just* properties/quantities described by T_b - so eliminate them, and only commit to the entities described by T_b.
- But T_t is not only really useful, but we want to say the higher-level ontology e.g. magnets, gases, cells, economies exist: 'Non-eliminative reductionism'
- Protect the higher-level ontology (*save the rainforest*, cf. Ladyman and Ross (2007)) by calling it emergent.

BROKERING A PEACE

- Anti-reductionists in philosophy of science, such as Batterman, are keen to emphasise the importance of the higher-level - it can't be eliminated.

- But elimination - whilst a part of some metaphysicians' views of reduction - need not be a part of reduction. Instead: vindication!

- Claiming that the entities of a reduced theory are emergent is one way of emphasising their importance - and that they shouldn't be eliminated.

- (Of course there are also pragmatic reasons why we don't want to eliminate older theories, such as computational tractability - but this doesn't help save the rainforest).

3. NOVEL AND ROBUST ENTITIES OF REDUCED THEORIES

In order that emergence and reduction go hand in hand, I need to show that a reduced theory T_t may nonetheless be:

- **robust**
- **novel**

with respect to the lower-level theory T_b.

3. NOVEL AND ROBUST ENTITIES OF REDUCED THEORIES

In order that emergence and reduction go hand in hand, I need to show that a reduced theory T_t may nonetheless be:

- **robust** (easier)
- **novel** (harder)

with respect to the lower-level theory T_b.

ROBUSTNESS

In performing the construction (reduction) we will see which differences don't matter - and so *which* lower-level details the higher-level is robust wrt.

- In the reduction of TD to SM, the choice of ensemble (canonical/microcanonical) doesn't matter: the regularities of TD are robust wrt this choice.

- (To a large extent, for TD it does not matter that the world is quantum not classical - *h* 'falls out' in the calculation of TD quantities.)

- In the ZZW case, we saw that over certain timescales, two or more particle correlations did not matter.

ROBUSTNESS

- More generally, T_t and T_b will have (some) different variables, and constructing T_t's equations and quantities from T_b will involve variable changes by e.g. summing/averaging - this is **abstraction**.

- Abstraction involves throwing away details - and so it is unsurprising that these details don't matter for higher-level.

ROBUSTNESS - TOO EASILY HAD?

- Robustness comes in degrees - some details matter, and others don't.

- Can we always find *something* X that the entities of T_t are independent of, and so robust wrt to changes to X?

- Perhaps, but one type of robustness is particularly interesting: **autonomy.**

AUTONOMY

The dynamical autonomy in the ZZW case generalises: a differential equation for *y* is autonomous of *x* if neither *x* nor *t* explicitly appear in the equation:

$$\frac{dy}{dt} = f(y)$$

So if we can describe the evolution of the variable Y_t *without* mentioning X_b then T_t is dynamical autonomous.

AUTONOMY AND CONDITIONAL IRRELEVANCE

- Dynamical autonomy will be less useful for non-dynamical theories, like the special sciences, or within physics - thermodynamics.

- But another condition: 'conditional irrelevance' specifies how the higher-level can be robust.

CONDITIONAL IRRELEVANCE

- Two sets of variables belonging to T_b and T_t respectively: X_b and Y_t

- Both sets of variables Y_t and X_b are causally relevant for explanandum E holding for some system S.

- But, given the values of Y_t, further variation in some other set of variables X_b are irrelevant, i.e. do not make a matter for E, even though X_b have much higher dimension, or number of DOF, than Y_t.

- Thermodynamics example: if the higher-level variable Y_t is the temperature of the water, then conditional on the value of this variable, the microdynamics (velocities of all the molecules, X_b) are irrelevant for considering the boiling point of water.

- This is **autonomy** in Woodward's framework:

> "autonomy here just means that the upper-level variables are relevant to the explanandum E and that the variables figuring in lower level or more fine-grained theories are conditionally irrelevant to E given the values of the upper level variables" (p. 20, 2018).

REDUCTION AND ROBUSTNESS

- To sum up: the reduction will show you which details do not matter, and so which lower-level details the higher level is robust with respect to.

- *Objection:* 'robustness' is too easily had?

- *Response:* we can understand robustness as a form of autonomy, which has a formal definition in dynamical theories, as well as a more general probabilisitic form in the causal modelling framework.

NOVELTY

- The time-asymmetry in SM is clearly **novel** wrt the underlying microdynamics.

- But will the behaviour described by T_t always be novel wrt to T_b?

- It depends on the type of reduction (cf. Crowther 2018, reduction_1 vs reduction_2 and diachronic vs. synchronic).

TWO TYPES OF REDUCTION

- Special relativity and Newtonian mechanics: an example of 'old-to-new' theory reduction.
    - T_t stands for 'tainted' theory
    - T_b stands for 'better' theory
- Call this 'horizontal reduction'

TWO TYPES OF REDUCTION

- Statistical mechanics and quantum mechanics: an example of reduction between different 'scales' or 'levels'.
    - T_t stands for 'top' theory
    - T_b stands for 'bottom' theory
- Call this 'vertical reduction'

- Horizontal reduction: T_t and T_b answer the same questions, but T_b is more successful.

- Nonetheless they give the same answers (to a certain degree of approximation) in a particular domain.

- Example: NM aims to answer the same questions as SR.

- Vertical reduction: the questions that T_t answers are different to T_b

- Vertical reduction: the questions that T_t answers are different to T_b

- The only way to answer 'what is the rate of change in entropy as gas approaches equilibrium' in terms of T_b to construct the irreversible equations of SM, T_t.

- Since they are answer different questions, one theory is not strictly more accurate than the other.

- Another way of putting this: in vertical reduction, T_t and T_b describe 'different subject matters'.

- An extreme example: the subject matter of psychology is different from physics.

- It is useful to distinguish the two extremes - vertical and horizontal reduction - to avoid the reductionism of Putnam and Oppenheim, who claim a completed physics would tell us about 'societies, minds and livings'.

- But contra Putnam and Oppenheim, the subject matter of psychology differ from physics - finding theory of quantum gravity will *not* give us an insight into human behaviour.

TWO TYPES, OR TWO ENDS OF A SPECTRUM?

- Not every case is neatly classified as vertical or horizontal…
- There are borderline cases (‘diagonal’?)
- Examples: CM and QM, & even TD and SM.

NOVELTY

- To sum up: in cases of vertical reduction, there is reason to think that the behaviour described by T_t will be novel wrt to T_b since in these cases the two theories answer different questions.

- But classifying cases as 'vertical' is tricky/vague.

- Indeed, Franklin and Knox (2018) observe that 'novelty is vague'.

- (Sociological observation: differing standards of novelty across different disciplines?)

CONCLUSION

- The irreversible equations of SM can be reduced to the underlying microdynamics — but the resultant time-asymmetry is *emergent.*

- A reduced theory T_t will often describe emergent entities:

    - Novel: if the reduction is 'vertical'

    - Robust: the reduction/construction will reveal which lower-level differences did not matter.

THANK YOU!

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COMPLAINTS AGAINST COARSE-GRAINING

Coarse- graining "seems repugnant to many authors"

- Uffink (2010, p.197)

"one of the most deceitful artifices I have ever come across in theoretical physics"

-Redhead (1996, p.31) as quoted in (Uffink, 2010, p.197)

'illusory'

-Prigogine (1980)

'subjective'

-Denbigh and Denbigh (1985, p.53)

"it is indeed a matter of philosophy rather than physics to decide if the coarse-grained asymmetry is 'real' or not"

-Davies (1977, p.77).

incompatible with scientific realism?

-Grunbaum (1973)

THE PROJECT HERE

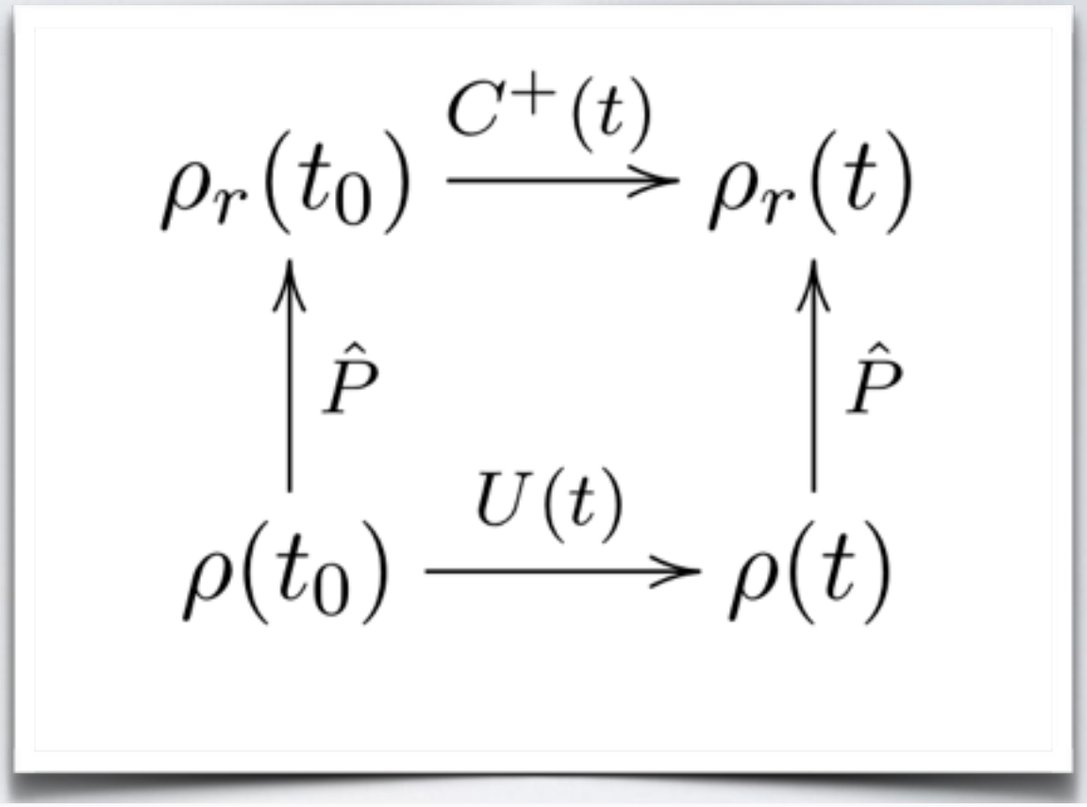
- To give a justification of coarse-graining:

A. (choice): what justifies the choice of coarse-graining projection?

B. (at all): why are we justified in coarse-graining at all?

2. WHY DOES THE RECIPE WORK?

- Coarse-graining dynamically enacted? Interventionism, Albert's GRW approach…
- Here: Wallace's initial conditions.



In *some** cases, coarse-graining at every time-step (the C+ dynamics) gives the same distribution at *t* as coarse-graining once at the end: **forwards-compatible.**

***Terms and conditions apply:** the reversibility objection shows that not *all* distributions will be forwards compatible and the recurrence objection shows that *no* distribution will be forwards-compatible for *all time*.

3.1 TWO OBJECTIONS

"Perhaps most worrying, the irreversible behaviour of Scg arises almost solely due to the coarse-graining"

- Callender (1999, p.360)

(Illusion): The asymmetry is a mere artefact of coarse-graining and so is an illusion.

(Anthropocentric): It arises from our perspective and so is anthropocentric.

3.2 AN UNSUCCESSFUL JUSTIFICATION

"The coarse-graining approach makes essential use of the observation that we only have access to measurements of finite resolution"

- Ridderbos (2002, p.66).

(Choice) - pick the coarse-graining ***P*** that matches our observational capacities

(At all) - we cannot tell the difference between ρ & ρ_r

4. AN ALTERNATIVE JUSTIFICATION

Why coarse-grain at all?

- Calculational intractability?

- Coarse-graining is an abstracting to a higher-level of description.

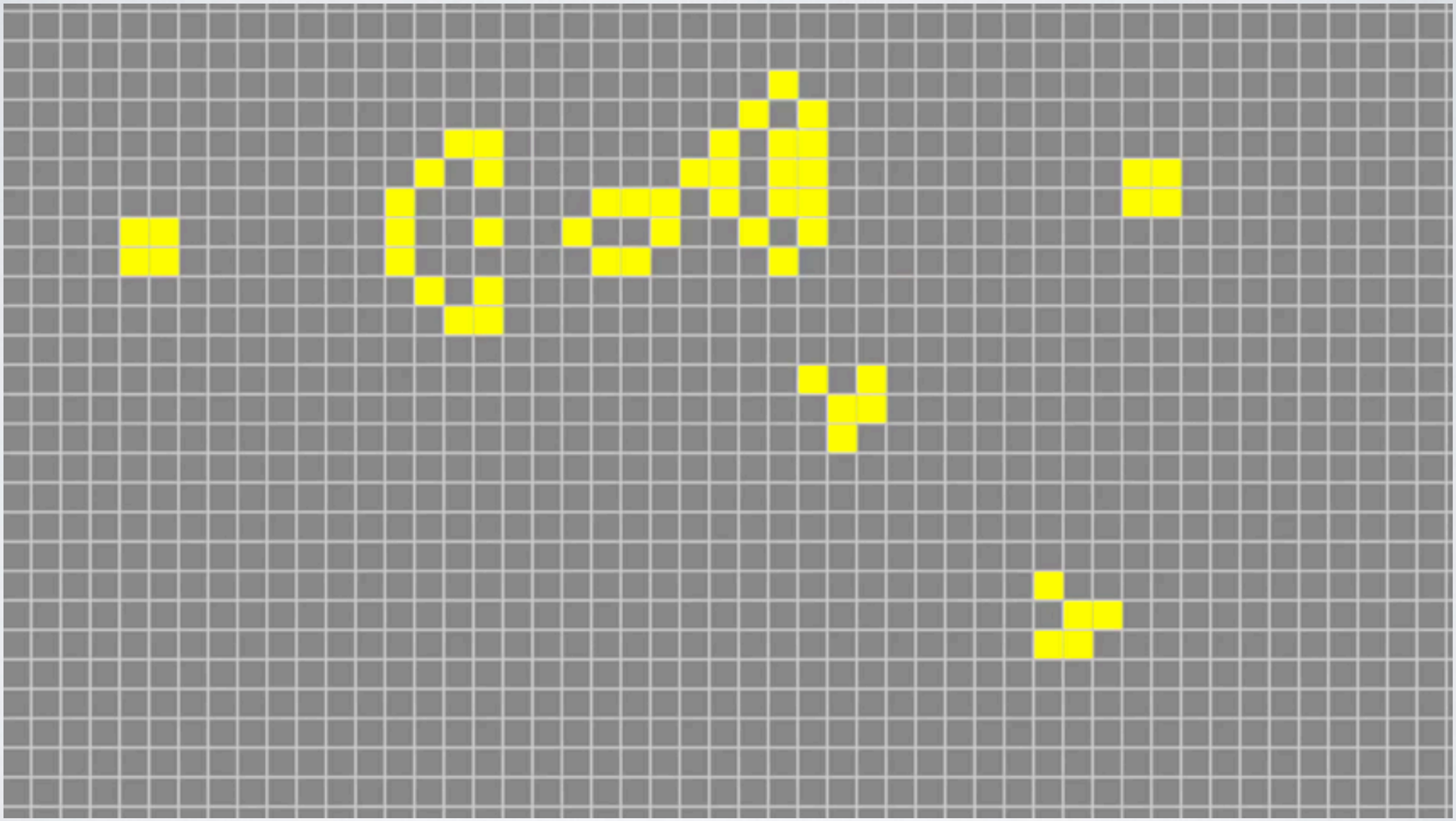
- But we don't just want to abstract to a higher-level of description: we want a theory of the goings-on at the higher-level.

- Not referring to lower-level details.

- This was achieved by the autonomy condition:

$$f(\rho_r) \text{ rather than } f(\rho_r, \rho_{ir})$$

THE GAME OF LIFE



(at all): coarse-graining at all is justified because it allows us to **abstract** to a higher-level of description.

(choice): the choice of ***P*** is determined by finding **autonomous** dynamics.