Effective Field Theories and Three Kinds of Autonomy

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Aims:

- To distinguish between different senses of ‘autonomy’.
- To argue that different types of autonomy can be found in different EFTs.
- To clarify which types are required to explain and/or are warranted by the success of the EFT programme.
- To weave in some broad morals about reduction and emergence.
- Overall: to raise questions and explore some ways to think about and interpret the physics (with minimal technical details). I do not purport to answer many of the questions. Though I hope that some answers will come out through discussion and the rest of the workshop.

Motivation

- Lots of folks talk about reduction and emergence quite generally: how does the world fit together? how does physics relate to chemistry? ...
- Castellani (2002) suggests that EFTs provide a good case study for examining such issues.
- Moreover EFTs are intrinsically interesting, as are the relations exhibited between different EFTs.
- Examining such issues may allow us to determine what properties we should expect/require future theories to display.
- In addition to disambiguation of different senses of 'autonomy', and relating these back to reduction and emergence, I respond to issues raised in current literature: specifically Bain (2013) and Williams (2015).

Preliminaries I

- By 'EFT' I mean effective quantum field theory. What I say may bear on classical effective field theories, but I haven't thought about this.
- By 'reduction' I mean derivation coupled with some explanation of the relations between variables defined at different length scales/energies.
- Reductionism (*qua* thesis about the world) is presumed unless we have some in principle anti-reductionist argument.
- Where we don't know the derivation – we don't have a top-down EFT construction available – I think we ought to be unsure about reductionism. But it would be hubristic in such contexts to deny it.

Preliminaries II

- Emergence isn't anti-reductionism: it's richer yet weaker than that.
- In fact, to the extent that EFTs are properly cast as emergent, then we may demonstrate that emergence is compatible with reductionism.
- Emergence corresponds to novelty and robustness.
- Novelty may be cashed out, in this context, as 'autonomy' – literally 'self-governing'.
- But there are many ways to understand autonomy.
- I discuss three types and relate them to formal properties of EFTs and some current philosophical discussions.

Outline

How to construct an EFT

- EFTs are theories with limited range of applicability.
- The most physically intuitive EFT construction starts with some Lagrangian, and integrates out high energy modes.
- One then ends up with a low energy theory with limited range which leaves out reference to higher energy particles and associated couplings.
- This is called ‘top-down construction’.

Autonomy$_1$: Derivational Autonomy

- Top-down construction is not always available.
- EFTs may also be constructed ‘bottom-up’ whereby known interactions, symmetries and empirical inputs are used to posit dynamics and construct an EFT in ignorance of higher energy goings-on.

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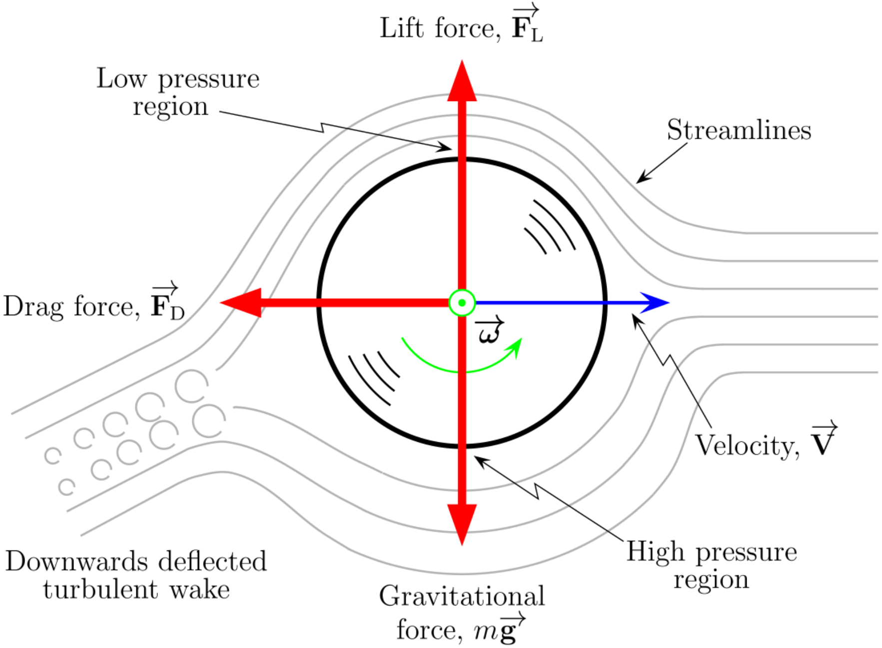
- Where we have bottom-up we don’t know. But that’s fine. Anti-reductionists cannot derive succour from ignorance. Only from in principle underivability.
- We do not have good reason to believe that there is underivability in principle. Thus derivational autonomy is not too interesting.


Lift force, $\vec{\mathbf{F}}_L$
Low pressure region
Streamlines
Drag force, $\vec{\mathbf{F}}_D$
$\vec{\omega}$
Velocity, $\vec{\mathbf{V}}$
Downwards deflected turbulent wake
Gravitational force, $m\vec{\mathbf{g}}$
High pressure region

Baseballs are Autonomous$_2$!

- One can describe baseball dynamics without explicit reference to high-energy theory.
- Experimental data input to baseball predictions need only be low-energy.
- Much in the world is like this.
- Some chaotic systems are not quite like this!
- This type of autonomy, in my view, is central to EFT. It's what EFTs require. And underlies their emergence.

What accounts for Autonomy$_2$ in the EFT context?

- Emergence and reduction are about inter-theoretic relations.
- We seek a theoretical property which would allow a constrained dependence of low energy physics on high energy physics.
- Thus we could arrive at low-energy theoretical autonomy coupled with some kind of reduction.

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- Thus we could arrive at low-energy theoretical autonomy coupled with some kind of reduction.
- In my view, renormalisability is the right property in the context of EFTs.

Perturbative Renormalisability

Duncan (2012, p.646)

A theory that is perturbatively renormalisable is “one in which the redefinition [renormalisation] of a finite number of Lagrangian mass and coupling parameters induces subtractions removing the UV cutoff dependence (up to inverse powers) of all the amplitudes of the theory, to all orders of perturbation theory”

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Stewart (2014, p.9)

i. Traditional Definition - A theory is renormalizable if at any order of perturbation, divergences from loop integrals can be absorbed into a finite set of parameters.
ii. EFT Definition - A theory must be renormalizable order by order in its expansion parameters:
    - This allows for an infinite number of parameters, but only a finite number at any order in ϵ.

Renormalisability I

$$\widetilde{G}_N(p_1, ...p_N; g, g_H, m, M, \mu) = \langle 0| \, T\tilde{\phi}(p_1)...\tilde{\phi}(p_N) \, |0\rangle_{\text{full theory}} \tag{1}$$

$$\widetilde{G}^*_N(p_1, ...p_N; g^*, m^*, \mu)[1 + \mathcal{O}(1/M^a)] \\ = \langle 0| \, T\tilde{\phi}^*(p_1)...\tilde{\phi}^*(p_N) \, |0\rangle \, [1 + \mathcal{O}(1/M^a)] \tag{2}$$

Renormalisability II

- Renormalisability amounts to the capacity for a given theory to define low-energy parameters such that, to leading order, higher-energy features and dynamics do not explicitly figure in the theory.
- The ability to remove reference to high-energy masses, couplings etc. – *subtractions* – and include such effects in changes to parameters – *reparameterisations* – leads to the kind of dynamical autonomy which is crucial to EFTs.
- Duncan (2012, p.613) "The intimate connection *reparameterization* $\iff$ *subtractions* ... is the essence of the proof of cutoff-insensitivity for perturbatively renormalizable theories".
- One may also talk of cutoff sensitivity: reparameterisation allows suppression of explicit cutoff dependence.

Does Renormalisability imply Autonomy$_2$?

- Paradigm case of failure of autonomy$_2$ is chaotic systems.
- In some such cases we do not have dynamics specifiable purely in low-energy, large distance terms. The dependence on high energy is unconstrained.
- Failure of this type of autonomy corresponds to the requirement to have dynamics even for slow, large objects which include elements specified at high energies.
- Deterministic predictions based on such non-autonomous dynamics require high-energy experimental input.

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- But many EFTs are non-renormalisable.
- Non-renormalisable theories have explicitly delimited range of applicability.
- Where non-renormalisable theories are renormalisable order by order we recover a more limited autonomy$_2$.
- It is more limited because the dependence is not purely through parameters – there are suppressed higher order terms.
- Renormalisation Group arguments suggest that all non-renormalisable effects can also be absorbed into reparameterisations.

What explains Autonomy$_2$?

- The Renormalisation Group?
- It provides formal criteria which facilitate the abstract description of how properties vary with scale change.
- It allows for specification of symmetry constraints which imply renormalisability.
- The use of the RG provides a general account of where fixed points are and thus where we can expect attractors and where we can expect cut-off insensitivity.
- RG shows that non-renormalisable terms are ‘irrelevant’ on approach to a fixed point and thus that non-renormalisable theories converge on renormalisable theories.

Outstanding questions:

- What is the scope of such RG arguments?
- Does the RG explain renormalisability or does it rather provide formal tools for assessing if renormalisability holds and what it implies?
- The RG arguments assume that we are dealing with eigenvectors of RG transformations. Where this isn't exactly true do the arguments apply?
- Can the RG guarantee in generality that non-renormalisable contributions will be restricted to modifications of parameters?
- Is renormalisability sufficient for autonomy$_2$? ... and for emergence?

The Autonomy of EFTs

- In the first part I briefly dismissed derivational autonomy. I then argued that renormalisability implies that EFTs are autonomous$_2$.
- EFTs, importantly, can be developed in ignorance of experimental results from high energy physics, and can be expressed in terms defined at low energy.
- Renormalisability, with the RG, accounts for this autonomy and thus suggests emergence.
- Some, however, argue that EFTs should also be natural.
- Naturalness may be viewed as an additional type of autonomy.

Autonomy$_3$: Naturalness?

- Naturalness failure is indicated by strong correlation between values defined at vastly different length scales.
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- There are various arguments in the literature that naturalness is worrisome because of fine-tuning.
- Williams (2015) interestingly suggests that naturalness corresponds to a kind of autonomy and that naturalness failure violates the 'EFT dogma'.
- I think that the 'EFT dogma' actually corresponds to autonomy$_2$ and that naturalness is a different kind of autonomy which we have no reason to expect in EFTs.
- However there may be additional reasons to be worried about naturalness.

An example of naturalness failure:

Williams (2015, p.87)

To see the sensitivity of $\lambda_2(\Lambda_L)$ to the cutoff-scale value$\lambda_2(\Lambda_H)$, set $\Lambda = \Lambda_L = 10^5$GeV and the UV cutoff at the Planck scale $\Lambda_H = 10^{19}$GeV, so that the ratio of scales appearing in the equation becomes $(\Lambda_L/\Lambda_H)^2 = 10^{-28}$. Now alter the 20th decimal place of $\lambda_2(\Lambda_H)$ sending $\lambda_2(\Lambda_H) \rightarrow \lambda_2(\Lambda_H) + 10^{-20}$. Plugging this value for $\lambda_2(\Lambda_H)$ into the above equation shows that this tiny change in $\lambda_2(\Lambda_H)$ causes the low-energy value $\lambda_2(\Lambda_L)$ to jump by a factor of 10^8!

Autonomy$_3$: Naturalness I

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- Is such dependence sensitive or insensitive?

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- Such parameters depend on high energy features.
- Is such dependence sensitive or insensitive?
- Can we vary values of couplings defined at high energy such that the low-energy theory remains the same?

Naturalness II

- For natural theories experimental results at low energy are compatible with a wide range of experimental results at high energy.
- For unnatural theories experimental results at low energy are highly constraining on experimental results at high energy.
- Both natural and unnatural theories may be renormalisable. I claim that the success of EFTs as effective theories does not depend on naturalness, rather it depends on renormalisability.

Naturalness II

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- Both natural and unnatural theories may be renormalisable. I claim that the success of EFTs as effective theories does not depend on naturalness, rather it depends on renormalisability.
- Nonetheless, what of naturalness?

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- Insensitively dependent theories are somehow more autonomous than sensitively dependent theories.
- And the incredible sensitivity of unnatural theories is really striking.
- But this is not an argument that unnatural theories are unacceptable.

How is unnaturalness possible?

- Renormalised theories absorb details from high energy scales into parameters at low energies.
- One way this is done is via the specification of bare parameters (say, defined at the high-energy cutoff scale) and counterterms. The physical parameters are equal to the bare parameters minus the counterterms.
- In natural theories one can vary the terms defined at high energy while leaving the low energy measured terms unchanged. As such the high energy parameters may not be thought of as physically meaningful.
- In unnatural theories the values of the parameters at high energies are tightly coupled to the value of the renormalised coupling at low energies.
- Such terms defined at high energy may thus be physical.

Taking Unnatural Theories Seriously

- Experiments at low energy in unnatural theories may provide highly detailed predictions about experimental results at high energies.
- Unnatural theories are thus more empirically defeasible.
- The extreme sensitivity of unnaturalness belies a failure of a certain kind of autonomy.
- However this autonomy is distinct from renormalisability.
- As such, I claim, naturalness is not required for an EFT.
- *Pace* Williams (2015) it ought to be acceptable to a proponent of the 'EFT dogma' to have an unnatural theory.

Autonomy_2 & Autonomy_3

- Autonomy_2 is an autonomy of dynamics from changes a system may actually undergo.
- Failure of autonomy_2 implies that the dynamics do not decouple.
- Autonomy_3 is rather about a decoupling of facts.
- If the facts were different at high energy, how much would that affect low energy descriptions?
- Decoupling of facts is not required for the development of low energy theories.
- Parameters are fixed for our world ... the supposed changes to facts are not changes the system may actually undergo.

Questions:

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- Ought we to expect EFTs to be (effectively) renormalisable? Yes!
- Ought we expect them to be natural? No
- Are there other ways to think about Beyond-the-Standard-Model projects motivated by naturalness?
- Are there other good arguments for naturalness which defend it as a type of autonomy?
- I don't like fine tuning arguments because I don't think that we have any well-motivated probability measures to apply here.

Summing up (I)

- Derivational autonomy is pretty common but philosophically fairly uninteresting in the absence of a good argument that it's an in-principle thing.
- Renormalisability is essential to the EFT programme. It's the kind of autonomy that EFTs have that's interesting. And it may be formalised and/or explained using the RG framework.
- Naturalness is a further kind of autonomy which is nice if you have it, but is not empirically or conceptually warranted by the EFT programme, and, as such, seems undermotivated.

Summing up (II)

	Autonomy_1	Autonomy_2	Autonomy_3
Emergence	$\sim$	✓	$\sim$
Reduction	✗	$\sim$	$\sim$

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