Aristotelian powers: Without them, what would modern science do?

Nancy Cartwright (LSE & UCSD)
John Pemberton (LSE)

November 2011

1 Introduction

Aristotelian powers, we maintain, are part of the basic ontology of nature – at least as nature is pictured through the lens of modern science. We defend these powers not on general metaphysical grounds but rather show their importance for making sense of contemporary scientific practice[1]. Powers are the best way to make sense of familiar methods for inferring and testing causal claims in contemporary science, from physics to economics; and in particular the use of what Pemberton has dubbed 'what-how-that evidence' (Pemberton, 2011).

Our powers are Aristotelian in that we suppose that what a power does when exercised is in the *nature* of that power. The powers we see at work in contemporary science have single outcomes: A different canonical effect implies a different power. This means that there may well be a very great many powers in Nature.

The Scientific Revolutionaries made fun of this kind of Aristotleanism: It seems to make a farce of scientific explanation. What makes heavy bodies fall? Gravity. What is gravity? That which makes heavy bodies fall. We by contrast embrace the proliferation of powers and argue that it neither undermines scientific explanation nor detracts from the achievements of science. Gravity does explain why heavy bodies fall and gravity is the power to make heavy bodies fall. The achievement of Newtonian science was first, in establishing the empirical fact that having a mass[2] confers on a body the power of gravitational attraction and then, in finding the exact strength and functional form of the canonical effect: GMm/r^2.

[1] In developing an account of powers from a consideration of science, we take ourselves to be furthering work started by Rom Harré (e.g. Harré and Madden, 1973).
[2] We have nothing to offer on what properties like mass are. They may be conglomerates of powers or perhaps something different from powers that can have some regular associations with powers.

Besides this singularity of powers, we are committed to a distinction between the 'canonical effect' of a power and the outcome that actually results. What happens when a power exercises depends on the context[3]. It generally, maybe even always, takes what Cartwright has called a 'nomological machine' to underwrite casual relations (Cartwright, 1999). Nomological machines produce the causal relations they do because of the way the exercisings of the various causal powers involved combine in the context of the machine to produce changes in the machine arrangement[4].

Nature produces nomological machines, as illustrated by the neuron in Figure 5. But so can we, as with the toilet cistern of Figure 4. So our account shares another of Aristotle's views: that art can help where Nature fails. We can use our knowledge of powers to build new nomological machines with new effects.

The focus on the 'canonical effect' of a power, which we call its 'contribution', is important. It matters not only to Nature – it is how Nature produces effects; but to us – understanding contributions and how they combine in context is central to how we predict what change a nomological machine will produce, how we are able to build new machines to produce new results, and how we provide evidence for causal claims.

Central to our account is taking change to be a coherent[5] process that unfolds through time. Here too we side with Aristotle, in opposition to both Hume and more recent writers who take change events to be adequately characterised by their start and end points alone[6].

We shall show how causal relations arise out of the operation of a nomological machine. This makes clear why a good account of the machine that would give rise to a hypothesized causal relation can provide strong evidence for that causal relation. We explicate how the machine arrangement dictates what can happen – it has emergent powers which are not to be found in its components.

This account of powers stands in opposition to a view that powers come with a detailed profile of the differing manifestations that will occur with a wide range of mutual manifestation partners. We outline some concerns about this account, which we take to conceal how both nature and we figure out what powers can do in a given context.

---

[3] We are thus developing a long-standing thesis of Cartwright concerning the combining of singular powers (e.g. Cartwright, 1983, p59). Others also hold powers to be singular, e.g. Lowe (Lowe, 2011). Molnar (Molnar, 2003, 12.1.3) and Mumford (Mumford & Anjum, 2011, Ch 2) are, as we understand, amongst those to share the thesis that what happens depends on the combining of the exercisings of singular powers.

[4] Our account of the role of the machine arrangement in dictating what can occur when powers manifest seems resonant with Molnar's account of how "non-powers", such as spatial position and orientation, can affect the outcomes of the working of powers (Molnar, 2003, Chapter 10).

[5] The nature of this coherence is a matter for science. For example, things, at the macroscopic level at least, are generally taken to follow a continuous locus of positions through time.

[6] We shall explore change more fully in later papers.

It might be objected that the account of powers we offer does not eliminate the need for laws of nature since it still leaves need for rules of combination that are independent of the powers in nature. So that unlike some other powers accounts, we may not have succeeded in getting governance back in to Nature. We concede that this may be so. There may be ways to get rules for combining powers into Nature itself in a way that fits a pure powers ontology and there may not. This remains work for the future.

2 Making sense of empirical science

2.1 Making sense of the evidence used by science

Cartwright, following JS Mill, originally defended powers in science in order to ground the widespread use of the analytic method, especially in physics and economics (Cartwright 1989). In both disciplines great efforts are made to understand what a cause would produce were it to act alone, with no other causes at work. In physics we create 'ideal' circumstances in highly controlled experiments. In economics we construct 'idealised models' to infer what a single cause would produce by itself ('Galilean thought experiments'). In econometrics we estimate parameters that represent what a single cause by itself contributes to an overall effect. One might naturally suppose the information gained is useless since in the practical world no cause ever acts alone. We spend great effort to learn what things do in circumstances that rarely if ever occur. Why?

In sciences making use of the analytic method – where classical mechanics is the paradigm -- what certain causes produce in isolation is treated as special. It is treated as a *stable contribution* that the cause can be relied on to make whenever it exercises properly, where a contribution is *stable* when it relates to what actually occurs in different circumstances in a systematic way. For instance, the total force on a mass will always equal the *vector sum* of the forces produced by all the causes of force acting, like the forces of gravity and of electromagnetic attraction and repulsion. Contributions from other kinds of powers combine by simple scalar addition - others in far more complicated ways – if the science is right.[7]

This, Cartwright has argued, is hard to make sense of using only regularity laws. But it is just what we should expect from powers. Powers have canonical effects; indeed, their canonical effects are part of what it is to be that power. The point about a power is that that *is* what it contributes, and it will contribute that whenever the power exercises properly. If the power is properly exercised by itself, the canonical effect will be what actually occurs. What results when several powers exercise together will depend in a systematic way on the canonical effects, or contributions,

[7]See Cartwright, 1999, pp 53 -59 for a discussion of other rules of combination. Pemberton, 2011 makes clear that the results of the combination will depend heavily on the constrainings, relations, and arrangement of the parts with powers, not just on what powers are present.

of each. So powers are just what are needed to underwrite the analytic method widely used across the sciences.

Here we propose a different kind of scientific practice that powers – and, we suggest, powers alone – make sense of, based on Pemberton's work on what-how-that evidence. Modern science uses three different kinds of evidence in support of causal claims: First, evidence encompassing things and their arrangements that bring about causal change (*what-evidence*); second, information about the processes of such change (*how-evidence*); third, the causal regularities that are brought about (*that-evidence*). More Humean accounts don't seem to allow much of this evidence – their ontologies are too parsimonious. They generally can make sense only of that-evidence, evidence of regularities.

Nomological machines are sufficiently stable arrangements of components and capacities or powers (Cartwright, 1999, p49) that can, under suitable circumstances, give rise to causal regularities. Nomological machines thus provide a principled basis for admitting "what-evidence".

How-evidence relates to what we call *change-processes*[8] (Pemberton, 2011).

2.2 Nomological machines: machine arrangements and change-processes

We suppose that the arrangement of powerful particulars in the nomological machine can give rise to a process of change involving these particulars. The machine arrangement provides the context in which the powers exercise.

The machine arrangement comprises a collection of particulars with properties that bring powers with them and other relations that help fix the arrangement, such as relative position or orientation. *Constrainings* are also typically a feature of machine arrangements. Examples of constrainings are: a molecular bonding, an interlocking of congruent shapes, a bolting together, a hooking together, a tying together (e.g. with a string, a tendon), a containing by a boundary (e.g. a cellular wall, a test tube). Constrainings impose constraints on the relationships among things. For instance, if two objects are enclosed in a spherical container of diameter d, their centres of mass must be less than distance d apart. Constrainings are on-going exercisings of powers of things in the machine that constrain the change that can occur to these things. Constrainings, at the mid-size level at least, often fall within the domain of the laboratory technician, the plumber, the carpenter, or other expert in the construction of arrangements of things. A piece of string pushed through a hole in a

[8] Our account of change-processes develops previous ideas of Pemberton (Pemberton, 2011) that mesh Cartwright's account of nomological machines, involving powers and their contributions, with features taken from the closely related account of mechanisms by Machamer, Darden, and Craver (Machamer et al, 2000), most notably their account of *activities*. Activities are important for understanding what the nomological machine does in changing arrangements from one stage to another.

bob and then configured into a knot has the power to hold fast to the bob, thus producing a constraining. When we tie the other end to a fixed pivot, we create a crude pendulum.

We may think of machines as beginning in a start arrangement. When its powers exercise, the arrangement may change into a new arrangement, perhaps with new powers – and this may change again into another arrangement. Each power produces its canonical effect, which is what is in the nature of that power to do. The overall change that occurs is the combination of the individual contributions in this context. We call this a change-process.

2.3 Examples of nomological machines and their change-processes

The following simple examples illustrate machine arrangements and change-processes across a range of scientific areas. In each case we show how science understands the repeatable change as a process in which a machine arrangement changes over time – and these changes are understood as the result of the combination of contributions of the individual powers in that specific arrangement.

2.3.1 Pendulum

Here is a familiar nomological machine: a bob tied by a string to a fixed pivot (near the Earth).

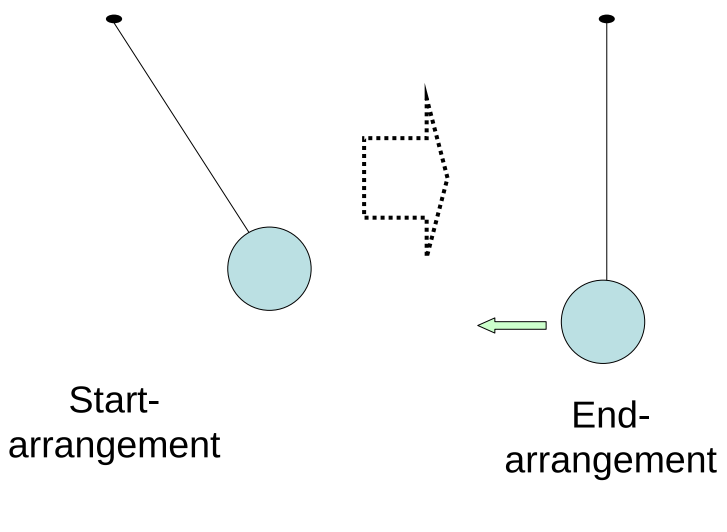

Figure 1

In the start-arrangement the bob is stationary and is released. In the change-process: the bob, by virtue of its mass, exercises its power to attract and be attracted by the Earth; the string exercises its power to pull the bob towards the pivot. The bob moves around the arc. There is flexibility in choosing an end-point –the bottom of its swing, say. The arrangement matters: The string could not pull the bob if it were not tied to it.

In modelling this situation, the forces due to gravity and the string are estimated as separate component forces; these are added to derive the resultant force on the bob and thus calculate its future position, velocity, and acceleration. This allows the movement of the bob to be neatly summarised, at least approximately, using well known equations. A more detailed definition of the change-process might be used, e.g. air resistance might figure in the arrangement; its effect is treated as an additional component force, and a model of damped oscillation results. For this nomological machine, as in many other mechanical examples, our empirical knowledge informs us that Nature's method of combining component powers is through vector addition. And we figure out which forces are added by inspecting the arrangement.

2.3.2 Wind pushing a blowable thing

The everyday empirical learning of children and adults in interaction with the world also makes use of nomological machines and change-processes.

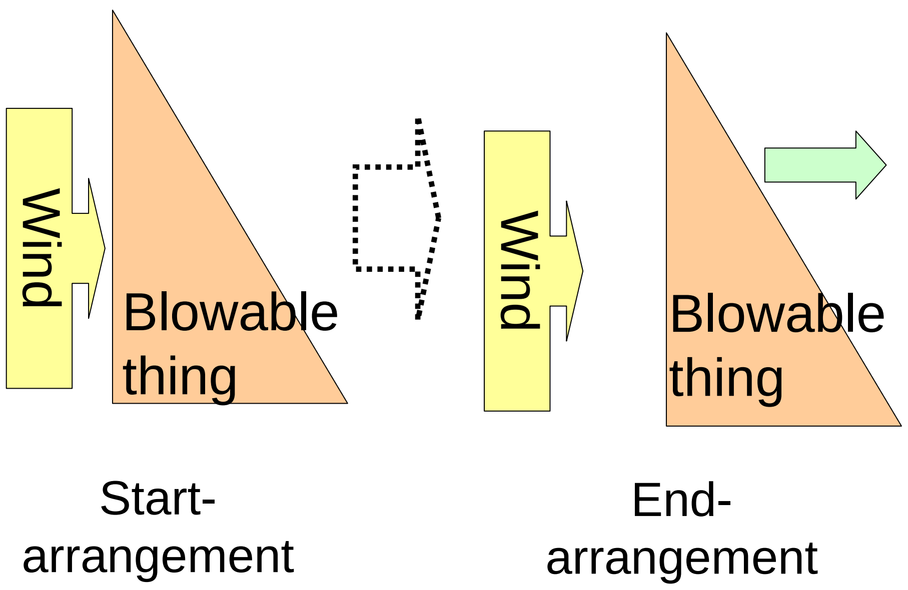

Figure 2

As a small child we may learn to blow toy boats across the bath, or plastic windmills to make them spin. Later we may fly kites; we learn to recognise washing on the line or trees being blown about. The change-process story is this: In the relevant arrangement, the wind exercises its power to push a blowable thing, and a blowable thing exercises its power to catch the wind and move. It is the combination of these exercisings of powers in the arrangement that gives rise to the change that occurs. We learn that it is in the nature of such winds to push blowable things. Note that the power has a single form of contribution. As children learn about the power of a wind to push, they are typically able to extrapolate to new situations: to their friend's toy boat, to a leaf floating on their milk. This is consistent with our suggestion that they are forming the notion of a single contribution of the power that applies across differing contexts.

2.3.3 Hydrogen oxygen explosion

Here is a simple example from chemistry:

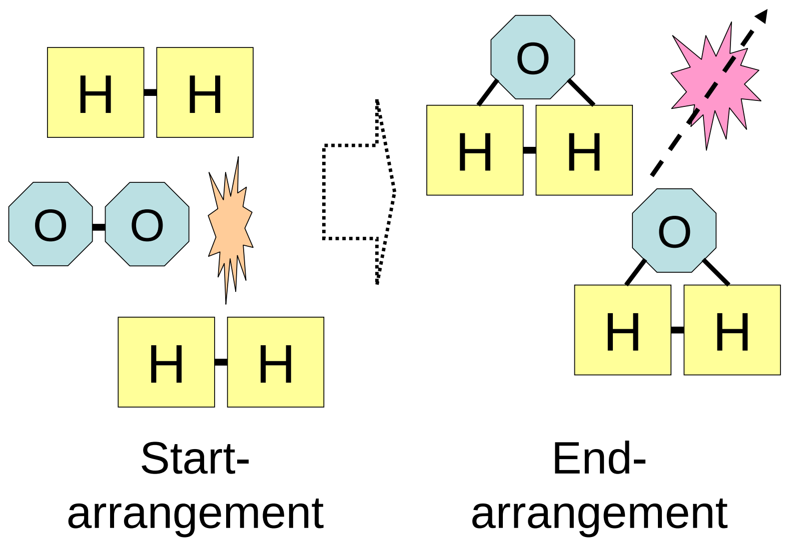

Figure 3

Hydrogen and oxygen atoms are initially arranged in bonded pairs. When the gas molecules are sparked, the increased excitation of some of these bonded pairs causes the individual atoms to break apart. Each hydrogen atom and each oxygen atom has the power to take part in the bonding of H^2O molecules (and in the somewhat complex and dynamic bonding that occurs in collections of such molecules, i.e. in water). As the hydrogen and oxygen atoms exercise their individual powers to bond to form H^2O molecules, energy is released which excites further molecules. Again, more detail might be included in the change-process story if desired, e.g. explicitly including the energy, its form, and its quantified amount.

2.3.4 Toilet cistern

Here is an engineering example:

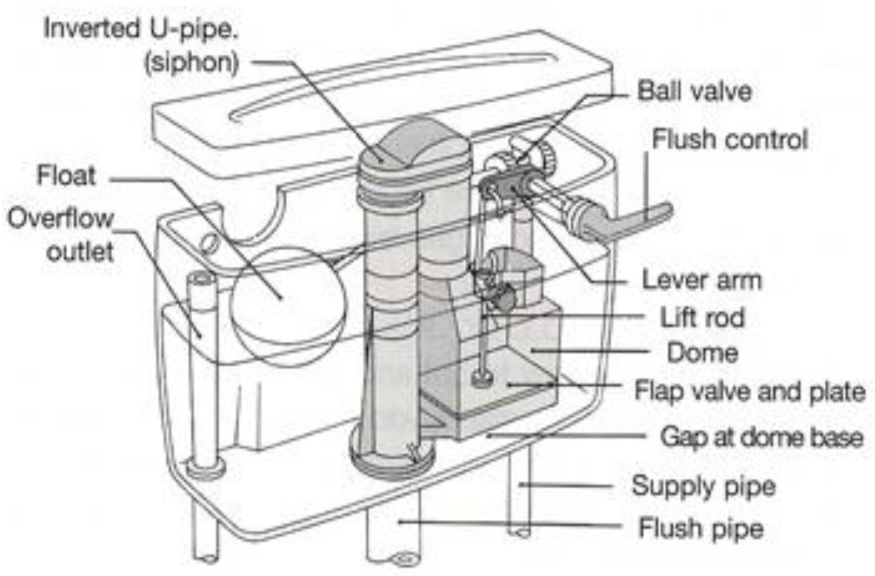

Figure 4

An account of the change-process might go like this:

> When the handle (flush control) is turned, the lever arm (which has the power to pull up the lift rod) pulls up the lift rod (which has the power to open the outlet valve) which opens the outlet valve (which has the power to release water from the cistern), which releases water from the cistern, which lowers the ball-cock, which opens the inlet valve,…

This is a nicely sequenced exercising of powers that makes transparent the sense in which the powers of each of the component parts work together in the machine arrangement to produce a change-process – the release of a flush of water and the refilling of the cistern.

2.3.5 Synaptic transmission

Typically examples from the biosciences are more complex since the relevant machine arrangements are more complex.

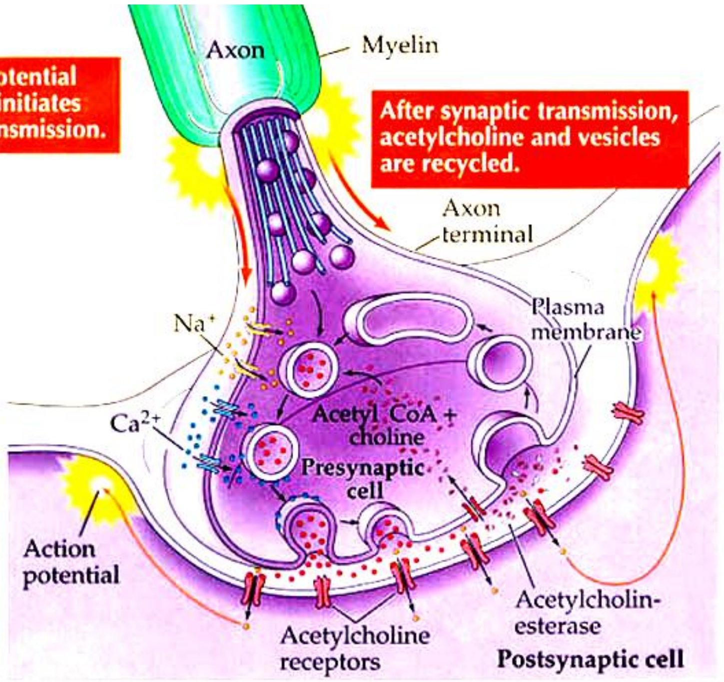

Figure 5

Here the story that biologists tell includes the movement along axons of action potentials, potential differences across the membrane that have the power to open sodium selective gates in the neuron wall, and how these open gates have the power to admit clouds of sodium ions into the neuron. As in our other examples, such stories tell how change arises from the machine arrangement as a result of the exercise of powers of the components, where the change occurs to the arrangement of the machine.

2.4 Evidence from the repeat operation of nomological machines

Empirical science is centrally concerned with machine arrangements and processes that are repeatable[9]. Repeatability allows evidence to be amassed to meet the demanding epistemic hurdles typical of empirical science. To obtain such repeat evidence, science focuses on type-level change-processes and type-level machine arrangements.

2.4.1 Science's focus on repeatability

The repeatability of experiments is at the core of scientific method. When we set up our physics or chemistry experiment in the right way, the method requires that we be able to reproduce the designated outcomes. In the biosciences the beating of a heart, the depolarisation of a neuron, and a vast number of other biological

[9] Although one-off change-processes are also often interesting, e.g. in crime investigation and history.

processes repeat. It is this repeatability that allows the study of these processes and of the structures that take part. Such studies form a central activity of bioscience, as documented in the subject's text books and journal articles.

The engineer, too, takes repeatability to be central – machines they design and build are expected repeatedly to produce a change-process sufficiently reliably, e.g. cisterns to flush, toasters to toast bread, lasers to lase. In everyday empirical learning repeatability is also central. Teaching our child to blow a toy boat across the bath assumes that repeating the blowing on future bath nights will achieve similar results.

But what does such repeatability amount to? Each token process just occurs once – it is not repeatable. Repeatability requires the type-identification of token change-processes with a change-process-type.

2.4.2 Type-level change-processes

When we identify a type of change-process as repeatable, we pick out some type of start-arrangement that dictates the change-process-type that can occur, thus fixing what can happen. The repeatability of the change-process, the sequenced exercising of powers arising from this type of start-arrangement, provides empirical evidence of how the relevant powers exercise and combine in this context. Typically, this evidence is complemented by prior knowledge of the relevant powers and their exercisings. In the case of man-made machines, it is this prior knowledge of powers that allows the design engineer to design the machine in the first place, putting the parts together in just the right way to produce the required change-process.

2.4.3 Nomological machines with repeat operability underwrite causal regularities, i.e. "that evidence"

This account of repeatable change-processes allows us to provide a more detailed account of how nomological machines underwrite causal regularities, typically taken to be laws of nature, and thus explicate more precisely the relationship between "that evidence", i.e. evidence about the occurrence and features of causal regularities, and the nomological machine's what-how evidence. Here is a picture of a nomological machine producing a causal regularity.

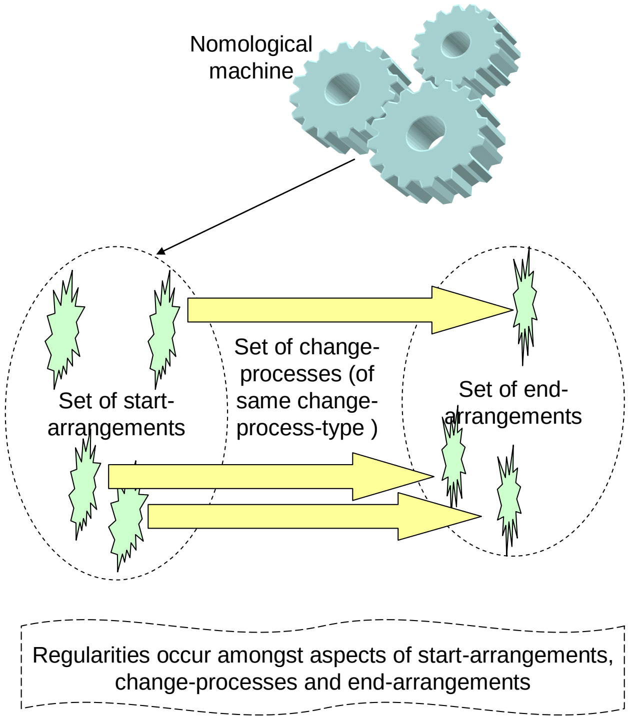

Figure 6

The start-arrangements of the nomological machine can give rise to change-processes of some change-process-type. Causal regularities summarise facts about relations between posited "causes" and "effects". These causes and effects are selected aspects of the start-arrangements, change-processes (e.g. taken to be events), and end-arrangements[10]. Examples of causal regularities are:

- the pulling of the chain (an aspect of the start-arrangement) is followed by a flushing (an aspect of the change-process)
- the explosion of hydrogen and oxygen (a change-process) produces water (an aspect of the end-arrangement

The nomological machine is real and the change-processes are real. The causal regularities are derivative from the repeat operation of the machine - they are real but epi-phenomenal.

2.5 Nomological machines with change-processes make sense of what-how-that evidence

How-evidence arises from the change-process, the production of the end-arrangement out of the start-arrangement via the combining of the contributions of the powers exercised in the context of the machine arrangement. Nomological machines with their change-processes thus allow us to make sense of the full range

[10] The adoption of a discrete time step here should be recognised as an explicatory device – in practice change processes interlink through continuous time.

of empirical evidence types used to support causal claims in empirical science: “what-how-that” evidence.

The following table illustrates the main evidence types with reference to the example of a toilet cistern.

Example: cistern flush	**Evidence-type**	**What-how-that**
Toilet flushes when chain is pulled	Regular association of “cause” and “effect”	That
Presence of machine – i.e. arrangement of components inside cistern (outlet valve, ball-cock, etc.)	Presence of machine (i.e. arrangement of components)	What
Outlet valve can release water, rod can pull open outlet valve, etc.	Components have suitable powers	What
The chain is securely hooked to one end of the lever; the lifting rod is bolted to the other end of the lever.	Constrainings are suitably implemented	What
Pulling of chain is followed by release of water and opening of inlet valve, then refilling of tank	Correctly sequenced occurrence of start, intermediate, and end arrangements	How
Rod experiences stress when cistern flush operates just when and how we anticipate (e.g. along its length, of credible strength)	Evidence of exercise of power	How

When we pull the chain the toilet flushes – a nice causal regularity, “that evidence”. And when we open the cistern lid we discover the presence of the machine responsible – a suitable arrangement of components that gives rise to a flush process. From our prior knowledge of plumbing, or perhaps by investigating the operation of this machine, we come to recognise what each component can do in this arrangement – the relevant powers of each component. We can look to see what constrainings are in place – e.g. the chain is hooked to one end of the lever; the lifting rod is bolted to the other end. These constrainings are consistent with the change-process we expect and with the ability of the machine to repeatedly instantiate the required start-arrangement. And when we pull the chain, we have evidence of the operation of the machine – the sequenced occurrence of start, intermediate, and end-arrangements of the components over a timescale and following a pattern we expect in light of the change-process-type, i.e. the flush process.

Does pulling the chain really open the outlet valve? Perhaps we are suspicious. We might attach a device to the connecting rod to measure stress. We find that the rod experiences stress just when we would expect given our characterisation of the change-process, and with credible magnitude and in the direction expected (i.e.

along its length). This provides additional evidence of the exercise of the relevant power.

The “what” evidence (the presence of a machine with suitable powers) and “how” evidence (the sequenced occurrence of the start, intermediate, and end-arrangements together with evidence of the exercise of the powers consistent with the change-process-type) adds to our regularity “that” evidence (the flushing of the toilet whenever the chain is pulled) to provide what-how-that evidence of causal regularities in the world.

Empirical science uses all three kinds of evidence and looks for all three kinds of understanding - the more the better.

2.6 How nomological machines and change-processes make sense of scientific methods

Many of the core activities of successful empirical science may be characterised, in terms of nomological machines and their associated powers ontology, as one of the following:

1. The identification of an arrangement of things in the world (i.e. some nomological machine arrangement), and the prediction of the near-future of these things (e.g. the future position of some planetary system, the arrival of a flush shortly after the chain is pulled).
2. The construction of an arrangement of things, including their constrainings, so as to control the local near-future (e.g. setting up some repeatable experiment in the laboratory; building toasters, computers, lasers, and other machines we plan to use in the world).
3. The intervention on some arrangement of things engaged in a change-process so as to amend the likely outcome (e.g. applying fertiliser to a field of crops, the application to a neuron of a ‘tetanus’, a high frequency train of stimuli that can induce long-tem potentiation (e.g. Craver, 2007, 3.2)).

Our empirical methods can also be understood as concerned with building knowledge of powers: knowledge of markers for the power, i.e. properties of things that carry the power (perhaps their microstructure, shape, or other feature, like mass), that tell us if the power is present; knowledge of the contribution the power produces; and knowledge of how contributions combine in change-processes in different types of machine arrangement.

To make use of such knowledge in a real world context, the sciences – and engineering – typically characterise the context as being of some machine arrangement type with which we are already familiar. We pick out some discrete collection of things and their properties, and certain of their powers, that we take to be relevant to some aspect of the near future of the context that is of interest. We then use qualitative and perhaps quantitative knowledge of the component powers together with knowledge of how they combine in this context to estimate the changes that will occur.

These methods of predicting or controlling the future are, everyone agrees, defeasible. As Anscombe notes, “Causation is not to be identified with necessitation,” (Anscombe, 1981, p136). We may agree that the hitting of a cricket ball by the batsman in a certain way caused it to reach the boundary. But if a ball, hit in just the same way, collides with a hapless woodpigeon at mid-off, then the boundary may not be reached. Omitting local things from our start-arrangement, in this case the woodpigeon, limits our predictive reliability. More typically, wind, rain, humidity, insects, etc. will vary the exact flight of the ball, so that an initial prediction that omits these is inexact.

In contexts where we have a high degree of control, such as the laboratory (or where we are lucky, such as astronomy), the effect of omitted factors on our predictions may be limited. In the blousy world of cricket balls, our predictions are typically less accurate. In any case, focussing on some discrete collection of features implies the omission of others that have some, hopefully lesser, relevance. Sometimes, at least, we can assess the likely degree of variation from our estimates to inform our strategy.

These methods for predicting make good sense given our powers/machine ontology in which Nature fixes the overall outcome by combining the individual contributions in the machine arrangement. Even better, our knowledge of component powers and how they operate under various constraints empowers us to make predictions about new arrangements – to design new machines and to predict what will happen in changed circumstances.

2.8 What powers do that laws can’t

This depends on what the laws are about. We have no quarrel with the claim that there are general truths connecting powers with features that ensure the presence of those powers. Having a mass brings with it the power to attract other masses; having the structure and components of a toilet cistern brings with it the power to flush water when the chain is pulled.

Hume taught that it makes no sense to distinguish between the obtaining of a power and its exercise. There are just, first, the features that, as we would have it, ensure the presence of the power and, second, the overall effect. We disagree. Our account is a powers account precisely because we take exercisings seriously as a central part of scientific ontology. When a power is exercised[11], its canonical effect is produced.

[11] Perhaps we should say ‘exercised without interference’. Can the power be exercised without the canonical effect occurring? For example, can the power to move another body closer be exercised without the other body being pulled? Maybe something prevents the pull despite the exercising? Although many metaphysicians allow for this, we have not discovered cases in the sciences where this happens.

This often differs dramatically from the overall effect that occurs. So the powers ontology distinguishes three distinct occurrences:

- the obtaining of the power
- the exercising of the power, which we here take to be synonymous with the canonical effect or 'contribution'
- the obtaining of the overall effect.

Having a mass ensures that a system has the power to move another system with mass towards it. In ordinary language, the first mass *pulls* the second even if the second does not move. *Pulling* is exercising the power to move another object closer, and that's just what it sounds like. One can relabel this with a different term – like 'the obtaining of the force due to gravity'. But that does not turn it from an exercising of a power into an event that should get admitted in a Humean ontology.

And we certainly have no quarrel with this relabeling. To the contrary, we argue that a central part of what science does – and should do—is to discover what powers exist in Nature and what ways there are of identifying when these powers obtain. For example, discovering the power to pull other bodies closer with precisely a strength of attraction GMm/r^2 and discovering that having a mass will ensure the presence of this power. This very specific power characterized by its precise canonical effect will naturally need a new, technical label.

Sometimes those who advocate an anti-powers or Humean ontology seem to suppose that if it's a technical scientific concept, and especially if it can figure in an equation, then it doesn't have to do with powers. Science at base deals with quantities that take values at space-time points, we are told. Suppose we agree. That doesn't do away with powers. For many of these quantities, like mass, science deals with them just because it has discovered that these quantities bring with them powers we have identified to obtain in Nature; others, like 'the force due to gravity', because they name exercisings. You may, in an attempt at a Humean space-time description, fail to mention what exercisings happen where and when, describing only the overall effects instead, like the 'total force'. But that does not mean that these exercisings are not there in the scientific image despite your failure to mention them. It is just by understanding what these canonical contributions are, that we – and Nature – figure out what the overall effect will be when a mix of powers are exercised together in a specific arrangement.

Suppose instead, in Humean fashion, that Nature does not have these canonical effects to look to. She has only laws that connect starting features and overall effects, which we shall suppose for the sake of argument may have nothing to do with powers. What must these laws look like if Nature is to consult them as to what is to happen in the sorts of real arrangements of things that we have been discussing, such as the set-ups in laboratories for repeatable experiments or the layout of the parts of a machine capable of repeat operability? To do the job these laws must be complex indeed.

Consider the toilet cistern in John's bathroom. When John pulls the chain, the lever turns pulling up the lifting rod that pulls open the outlet valve releasing water to flow and push against the flanges of the valve to open it further. The laws that dictate what happens must reflect the exact shapes, arrangement, and constrainings of each of the parts. They must allow too for the perishing in the rubber seal, the temperature of each of the parts, the temperature gradients around the water in the tank, the turning moment of the water and its other internal flows, the vibrations from the passing bus, the gravitational effects of sufficiently local objects e.g. the Moon, electro-magnetic effects on the water due to local cables, and no doubt millions more such factors. And they must be exact in each case.

Our objection here is just like that we will make to the causal profile account that identifies a power with what it does in every single possible circumstance. There are way too many of these and they are way too complex.

Sometimes the 'laws only' theorist pretends that this superinfinitude of laws are all instances of some finite set of simple laws. That has two drawbacks. First, the usual one: This is a huge promissory note. In areas we and others have looked at – the physics of lasers or superconductors, the use of economics theory in auctions for the airwaves, or the construction of everyday machines – we have never seen this work. In many cases there is good reason to think it can't work, and in many others, no obvious way to set about doing it.

Second, it sweeps big issues about arrangements under the rug. If a bunch of forces are present together, the question of arrangement seems not to come up. They just add by vector addition. But what if you have a lever, a valve, a pulley and some flanges? Do you get a toilet cistern? Or…? The canonical effect of a lever combines differently with that of a pulley depending on what arrangement they are in. What kind of finite set of simple laws will encode the infinitude of possibilities? Perhaps there is one that can. But why think so? Mere metaphysical prejudice against powers is not a very convincing reason. Which brings us to our basic objections to laws, both the small set of simple ones and the superinfinity of super complex ones.

These laws are unnecessary. We do not consult such laws to make predictions nor to build devices that work as we want. We consult our knowledge of what features bring what powers with them and of how these achieve what overall effect in specific arrangements. Why should we not suppose it is just what Nature does? After all, if the information is there for us, surely it is there for Nature too.

Finally these laws, even if they exist somewhere for Nature to consult, are not very helpful for us. On the laws picture, successful scientific descriptions of what happens in specific circumstances supply a set of highly detailed laws covering specific situations. How are we to use this to construct knowledge about what will happen in other situations? In the powers ontology, the powers of things in their specific arrangements are there in the actual situation. They are what Nature looks to to settle what should happen next. And they are what we look to to achieve the outcomes we aim for.

We design situations to have suitable arrangements of things, powers, constrainings and shieldings so that the powers we wish to dominate the overall outcome do so. We necessarily omit many things, powers, and details of the actual arrangement, Often this turns out to work: The contribution to the overall outcome from the omissions is sufficiently small. Sometimes it is not. Now we must redesign, adjust or mend and try again. When the arrangements work as expected, this provides evidence about the operation of the powers in this context – and we build our knowledge of powers, the things that ground them, and what the powers do in various types of situation by bootstrapping from such evidence.

The laws theorist would no doubt like to adopt some similar story to argue that empirical evidence for our complex change-processes provides evidence for those simple laws they like so much. This is just what we have argued is difficult to justify. But even were the laws theorist to succeed in developing an account that does not appeal to powers, their putative laws would surely accord with the findings of current science – they could be neatly summarised in powers talk. Perhaps then the laws theorist might pro tem proceed *as if* the powers account of science were correct, whilst retaining a belief that powers are merely talk. But this would already acknowledge the practical accuracy of a powers account for making sense of the strategies of modern science, especially the use of “what” and “how” evidence.

We adopt powers on just such pragmatic grounds, rather than on any metaphysical basis – science in practical interface with the world makes do with powers. So why posit laws that cover every possible case and maintain faith that this approach can one day be empirically justified? As Mumford notes, laws are themselves metaphysically extravagant (Mumford, 2004) – surely parsimony dictates that we give up a laws account, at least until it can be better justified. Powers provide a coherent ontology that makes sense of the practice of science. Laws as yet do not – and there seems little reason to suppose they will do so any time soon.

3 Some concerns with a causal profile account of powers

Our examples show how science calculates overall outcomes by combining separate contributions from distinct powers in a specific arrangement. This is what motivates our Aristotelian account in which powers have a single canonical effect: One power, one contribution. It is in the nature of the power to produce just that contribution. This account is likely to be troubling to metaphysicians who favour a profile account of powers, on which, roughly, a power is characterized by a causal profile. A causal profile can be represented as a set of ordered pairs, where the first member of each pair is a set of mutual manifestation partners, and the second member is the manifestation that can occur when the associated manifestation partners obtain. In deterministic cases, when the first member of the pair obtains, the second (the manifestation) is supposed to obtain as well; in the case of probabilistic causality, the latter obtains with a certain probability; and perhaps even erratic operation can be allowed, where the manifestation obtains sometimes, but with no fixed probability.

Since the manifestation partners are themselves properties/powers (in the varying senses proposed by different accounts), on this metaphysics, the causal profiles that define the different powers that exist in the world must all be consistent.

We have a number of worries about this account:

1. The causal powers seem to be analyzed away by the conditionals that can be read off from their causal profiles. Of course, if you identify properties as just conglomerates of powers, you can say that both the antecedents and the consequents of these conditionals are causal powers. Still, the whole story doesn't look much different from when you don't say that. So this looks too much like analysing powers away into conditionals to count as a robust powers account.

2. One of the central lessons we take from science is that arrangement matters. Some metaphysicians talk as if arrangements are just another member of the set of mutual manifestation partners. We don't see how to make sense of this. Alternatively, the first member of the ordered pair could be, not a set, but a total situation – i.e. different causal interferences, linkages, etc imply different situations. But this does not seem to clarify how arrangement is to be managed within the profile.

3. For many properties the causal profile will be 'dense': It will have the cardinality of the real number line, or higher. Distance r and mass m seem to be mutual manifestation partners with M in producing a force contribution GMm/r^2 and that will be true for all values of r and of m, across the two continua.

4. Since there is no mention of contributions, it looks as if the second member of a pair in the causal profile will be the overall outcome. But then we must admit not just uncountably many items in the causal profile, but the causal profile is also totally open-ended and indefinite. In favour of our view, there is at least a recognizable pattern to what would be the causal profiles for separate singular causal powers. For instance, for the power of gravitational attraction that objects of mass m always have, the first member of the ordered pair is always a mass a distance r away; the second, always a (component) force GMm/r^2. But there's no system to the features of the first members of causal profile pairs when the second member is the overall result (in our example, the 'resultant force'). A mass m can get itself into any arrangement with any number of masses and charges. Moreover, of this vast undisciplined set of features that occur as first members in the profile of the causal powers that the sciences study, it would seem that the ones that are instantiated are generally a set of measure zero.

5. It seems as though powers do not emerge at higher levels, but are prewritten into the (necessarily consistent) causal profiles of each of the components. It is not clear how to avoid the implication that all causal powers must be written in to the causal profile of some putative lowest level things, and that these profiles then encompass all the possibilities of the Universe.

4 The emergence of powers and things

On the account of causal powers that we draw from science, each power has a single canonical contribution and rules of composition of various sorts apply. The causal power that results from a specific machine arrangement, e.g. a toilet cistern, comes in to existence when the arrangement comes into existence. It is not there lying dormant in the causal profile of all the constituent parts, along with non-denumerable infinities of ones that will never obtain. When a token start-arrangement gives rise to a token change-process, this token start-arrangement has the power to produce this token change-process – this power emerges just when the start-arrangement is put together.

Such start-arrangements may be temporary and one-off. A one-off arrangement supports a causal relation between the token start-arrangement, change-process, and end-arrangement, or between some chosen aspects of these tokens, but not a broader regularity.

Where a machine arrangement, or some part of an arrangement, remains coherent through time (e.g., where the constrainings are sufficient to maintain an on-going arrangement of some of the components), we typically recognise this on-going coherent arrangement as a thing, e.g. a pendulum, a kite, a toilet cistern, a neuron, a diamond carbon-lattice. Such things may support the repeated instantiation of some start-arrangement type.

In a repeatable process, start-arrangements of the right type to gives rise to this kind of process exhibit the power to produce a change-process of this type. Where a thing-type supports the repeated instantiation of such a start-arrangement-type, things of this type possess the relevant power, e.g. a pendulum can oscillate, a kite can fly, a cistern can flush, a neuron can fire, a diamond can scratch glass.

This account ascribes powers to things that are themselves sufficiently stable arrangements of other things. We do not restrict the ascription of powers to components, and we avoid speculation about whether there are basic powers from which all else derive.

This conclusion has major implications for debates about levels and about reduction. The arrangement of parts is immanent in the whole but not in each of the parts. Machine arrangements can have emergent powers not possessed by each of the parts. This is only likely to seem troubling if we pay insufficient attention to the role of the machine arrangement in dictating how singular powers may combine. This account of singular powers and their combination lends support to the autonomy of the special sciences and provides a challenge to reductionism.

As we acknowledged above, this account of powers leaves the need for some account of composition. Perhaps component powers come with rules for what will be produced overall when they act in combination in specific arrangements with other successfully exercised powers. But this seems unnecessarily complicated.

Consider by analogy: Each of us having a rule for calculating what we would do should we get together seems far more efficient than each of us having built in a dense set of predetermined outcomes for 'all' of the indeterminate situations we might possibly encounter. We leave this as future work.

References

Anscombe, G. E. M. (1981). *Metaphysics and the philosophy of mind.* Blackwell.

Cartwright, N. (1989). *Nature's capacities and their measurement*. Oxford: Clarendon Press.

Cartwright, N. (1999). *The dappled world: a study of the boundaries of science.* Cambridge: Cambridge University Press.

Craver, C. F. (2007). *Explaining the brain.* Clarendon Press.

Harré, R. and Madden, E. H. (1973). *Natural powers and powerful natures.* Philosophy 48.

Lowe, E. J. (2011). *On the individuation of powers.* In Anna Marmodoro (Ed.) *The metaphysics of powers.* Routledge.

Machamer, P., Darden, L. and Craver, C. F. (2000). *Thinking about mechanisms.* Philosophy of science, 67 (March 2000).

Molnar, G. (2003). *Powers.* Edited by S. Mumford. Oxford University Press.

Mumford, S. (2004). *Laws in nature.* Routledge.

Mumford, S. and Anjum, R. L. (2011). *Getting causes from powers.* Oxford University Press.

Pemberton, J.M. (2011). *Integrating mechanist and nomological machine ontologies to make sense of what-how-that evidence.* http://personal.lse.ac.uk/pemberto