Implausible Engineering – Episode 7a: Self- replicators

There's an oft-cited meme of the grey goo – were one or more supposed nano-machines set about converting organic matter into copies of themselves and thereby multiplying exponentially until they have consumed the entire ecosystem in a process called ecophagy, leaving behind grey goo – an amorphous mass of nothing much except those nanomachines. Further extrapolation of this concept gives them the ability to also break down and reconstruct inorganic matter, thereby giving the nanomachines the ability to convert an entire planet to grey goo.

But hang on… there are physical limits to what's achievable here. There are myriad biological examples of organisms, small and large that consume other organisms and replicate themselves with the derived components and energy. But nothing consumes something else with 100 per cent efficiency. There's plenty of microorganisms that can consume bits of you and use those bits for energy and raw materials to replicate themselves – and potentially kill you in the process. But they don't consume all of you. Once you're dead, a much wider range of organisms will move in to consume the various remaining components of you through a range of different mechanisms, until it's all gone or is otherwise soil fertilizer.

Going from the other direction, there's lots of large organisms that eat 100% of smaller organisms, but their digestion of those smaller organisms is only partial, leaving waste behind – which is then dumped, to be later processed by a range of other organisms. In other words, it takes an ecosystem to consume an individual organism, particularly one at the macroscale. It's hard to believe you could pack all the myriad chemical and mechanical breakdown strategies employed by Earth-based ecosystems into one single organism, particularly one at the nanoscale.

Breaking down inorganic matter is even more implausible. Faced with a lump of granite your options are to heat it to furnace temperatures, blast it with ionizing high energy gamma rays, mechanically break it down or use chemicals. It's only the last option that could be feasibly exercised by a nano-machine. And if you going to convert a chunk of granite into more nanomachines, the nano-machines have to be made of granite or it's primarily silicone-based breakdown products. The reason why ecosystems can recycle dead individuals into live individuals is that the materials are common to all – carbohydrates, amino acids, lipids and a few trace elements. You just break things down into their components and then build them up again.

People imagine future technologies where we'll have magical machines that can break down anything into its elemental components and then feed those components into a 3d printer to build them up into something completely different. Or you just apply the even more magical Star Trek transporter and replicator technologies that can break down and rebuild anything you want at the touch of a button. But even if there are such technological possibilities to come, there still has to be energy and heat involved. So a nanomachine trying to break the chemical bonds of an adjacent inorganic material risks destroying itself either from the energy it must generate to break those bonds or from the exothermic reaction resulting from the bonds breaking. It seems vastly easier to break something down by firing a phaser at it from a distance or heck just hit it with a sledgehammer. As for putting components back together, it's similarly unclear why a nanomachine would be particularly good at this – 3d printers are relatively complex machines with lots of moving parts and Star Trek replicators are, well, magic.

What's been proposed for space exploration is to send out a robot spacecraft made of materials that are relatively ubiquitous and can be sourced across the Universe from most planetary systems, including ours. So you get rocket fuel from water, solar panels from lunar regolith or just find a planet like Earth and dig it all up again.

Thinking to date does identify these materials, though it still appeals to somewhat magical technology whereby one robotic spacecraft can replicate itself without the need for ore refineries or metal smelters – but OK, it's not completely implausible. But expecting nano-machines to achieve all this does seem: a) implausible and; b) largely unnecessary.

Implausible Engineering – Episode 7b: Black hole starships.

The future is full of amazing energy sources, Helium-3 fusion reactors, matter-anti-matter generators, and hey now there's black hole engines too.

So, imagine a rotating black hole which like any black hole has an ergosphere, which is a region above the event horizon, but where black hole's gravitation has noticeable relativistic effects on space-time in that region. Remembering it's a fast-rotating black hole, you get relativistic frame-dragging within that ergo sphere. So, it's as though the ergosphere acts like a thick atmosphere so an in-falling particle will appear to a distant observer as though it's moving around the blackhole in the direction the blackhole is rotating.

But, from there it's best just to say there's a whole bunch of complex stuff going on. So for example, any object falling towards a large compact mass generally spirals in, since routine spacetime curvature due to gravity will tend to put falling objects into a partial orbit – or perhaps even proper orbits if they are falling at just the right angle and velocity. Frame-dragging is something else again. It's seen very slightly in the once-mysterious precession of Mercury's orbit, where from Mercury's frame of reference it's just doing a normal orbit, but from a distant observer's perspective, the perihelion of its orbit (the point in its orbit at which it gets closest to the Sun), keeps shifting very slightly – which was a baffling mystery until general relativity came along.

Anyhow, the situation isn't dissimilar to a spacecraft gaining speed from a gravity assist maneuver where it steals some of a planet's orbital velocity by dipping into the planet's gravitational field, being pulled along by it and then leaving the planet with more velocity than it had when it arrived. In the case of the black hole, it's not its motion, but its spinning that contributes energy to the spacecraft.

Anyway, through what's known as the Penrose process, you drop something into the black hole, it gets dragged around in the ergosphere and then fires its rockets to push itself up out of the black hole. When you start pushing people for details of how exactly that's going to work, they'll tend back down to acknowledging it's a thought experiment. So, the thought experiment goes that the object you've got essentially splits in two, one half going into the black hole as propellant and the half being pushed out. The best analogy is a spacecraft firing its rockets, where the propellant goes into the black hole and the spacecraft comes out, but how such a craft and its complex machinery could survive the spacetime distortions that occur that close to a black hole event horizon are not explained.

But anyhow, the small amount of thrust plus the big acceleration provided by the spun-up frame-dragging ergosphere work together to accelerate the object out of the ergosphere. And it comes out with a lot more energy than it went in with. The easiest way to think about this is to remember anything falling into a black hole gets red-shifted, so lower energy, while anything coming out gets blue-shifted, more energy. So, through the Penrose process you gain energy from the black hole's spin, slowing that spin by an exceedingly tiny amount and gaining a truckload of energy in return - indeed an absolute %$#@load of energy according to the math. So, if it is a spacecraft it emerges with an accompanying blast of high energy gamma rays.

How you then harness that energy is not fulling explained either – building a Dyson sphere around the black hole seems to be a standard gambit.

From here, we can do a bit more hand-waving away of pesky details and have manageably sized black holes that are somehow manufactured then put into orbit around your planet or otherwise held in some kind of containment field to power a starship. See we got there in the end.

The part of the story about one bit goes in and the other bit comes out, and the black hole loses a bit of energy as a consequence, may sound reminiscent of Hawking radiation - and apparently there's some similarities in the math. Indeed, it's not unusual to read popular science articles or just plain science fiction where a black-hole-powered starship is actually running off Hawking radiation – although Hawking radiation alone is likely to deliver orders of magnitude less energy than the Penrose process would.

And what the heck – a bit more hand-waving and you can have a Penrose process generator in your backyard which will generate power just by dropping garbage scraps into its mini black hole. Anyhow, it really is the case that the math of black hole engines work, you then just need a few black box miracle components to make the engineering work.