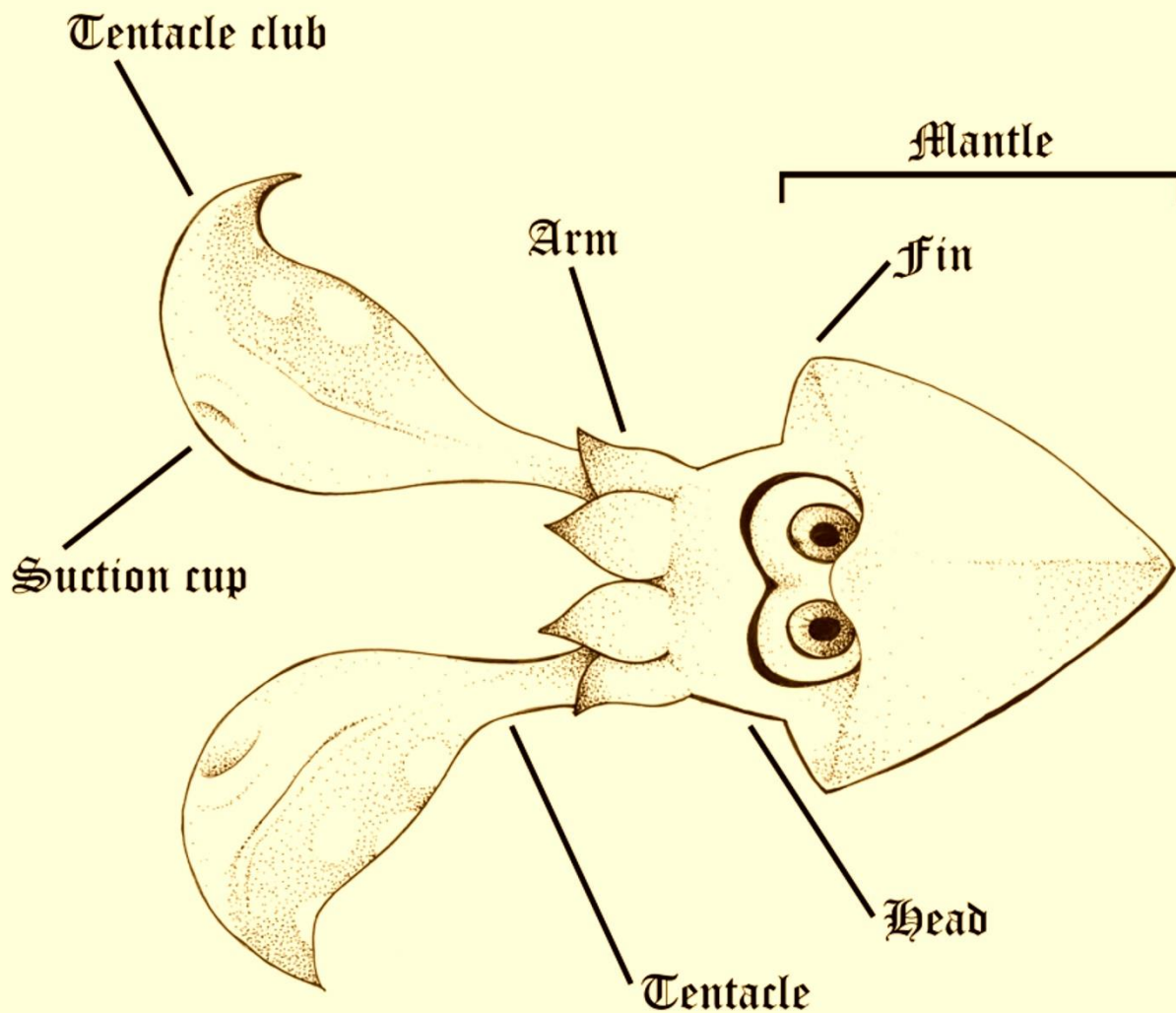


Inkling Anatomy (*Nitendoteuthis splatoonensis*)



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Cover art: Inkling Anatomy (March/2016). Drawing by Barbara M. Tomotani, text by Rodrigo B. Salvador.

Fan art of the inkling character from Splatoon (Nintendo, 2015), drawn as an old naturalistic illustration. The species' "scientific name" is just to give the illustration more flavor and, thus, is not valid by the ICZN (1999).



The biology of giant war centipedes

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Gears of War is one of the best video game franchises out there. Currently, it counts with four entries for the Xbox 360 and a remake of the first game, recently released, for the Xbox One. The games are not only brilliant shooters, but also feature some remarkable creatures. My favorite one is the serapede (Fig. 1). Its name, obviously, comes from Sera (the planet where the games take place) and centipede (the animal on which the creature was clearly based). They were described as “15 ft. long centipede[s] you see in ‘50s horror flicks” (Gearspedia, 2015).

Serapedes are used in combat by the Locust Horde, due to their awesome abilities (Gearspedia, 2015). For starters, they have a gigantic size (in the games they seem to be ca. 3 m long, though the Gearspedia gives 15 ft., which is roughly 4.5 m) and strong pincers to chop poor soft-bodied human soldiers. Moreover, they have steel-like carapaces – a bulletproof armor, if you will. If that was not enough, they can spray acidic poison from their mouths. Last but not least, they can, as the game tells you, “shoot lightning” from their pincers; to put it less dramatically, it is an electric discharge.

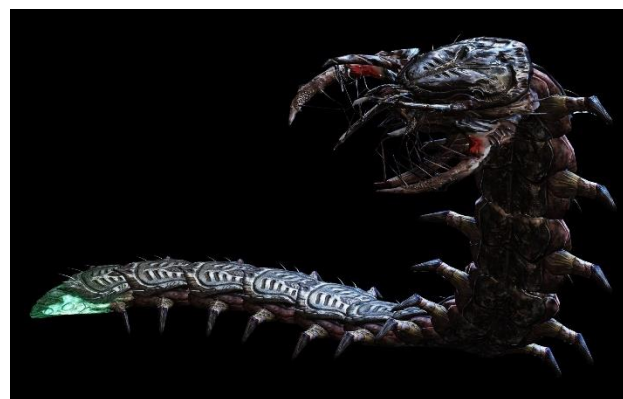


Figure 1. A serapede (original model from the game).

Here I will investigate if, from a biological and paleontological perspective, serapedes could possibly exist. I can say in advance that the answer is “partly” and I will explain why for each of the four serapede features/abilities: gigantic size, heavy armor, acid/poison spray and electric discharge. But first, we will need a primer about real-world centipedes and similar animals, the group called Myriapoda.

MYRIAPODS

For those familiar with biological classification, it is enough to say that the subphylum Myriapoda belongs in the phylum Arthropoda. Now in English, it means that

myriapods are a sub-group of arthropods. Arthropods are the most diverse group of animals on Earth and, myriapods aside, they include crustaceans, hexapods (insects and some wingless creepy crawlers), chelicerates (arachnids and some strange creatures) and the extinct trilobites.

The myriapods count with over 13,000 living species, all terrestrial (Waggoner, 1996). As a matter of fact, the fossil millipede *Pneumodesmus newmani*, is the first terrestrial animal we know of (Wilson & Anderson, 2014). It dates from the middle of the Silurian Period (ca. 428 million years ago).

Myriapods are divided into four classes: Chilopoda, Diplopoda, Symphyla, and Pauropoda (Fig. 2). A fifth class is known from fossils only and it is called Arthropleuridea (I'll come back to it later). Chilopods are the centipedes. Diplopods are the millipedes. Symphylans are commonly known as "pseudocentipedes", since they closely resemble centipedes, but are much smaller and translucent. Pauropods are more closely-related to millipedes and look somewhat like very short versions of them (although some can look more like centipedes).



Figure 2. Examples of myriapods belonging to the four extant classes. Clockwise from top left: Chilopoda (centipedes), Diplopoda (millipedes), Symphyla and Pauropoda. (Image from Animalparty, 2014, Wikimedia Commons.)

That's all very cool, but what is the difference between a centi- and a millipede? By their names alone, one can imagine that the former has a hundred feet, while the latter has a thousand. Of course, these names are merely a useful simplification and reminder, but centipedes have less feet (actually, legs) than millipedes. The "leggiest" animal of all is a millipede: with 750 pairs of legs, *Illacme plenipes*, from California, which is just 3–4 cm long (Marek & Bond, 2006; Marek et al., 2012).

The true difference, however, lies in how many legs they have per body segment. Each segment of centipedes has a single pair of legs, while each segment of millipedes has two pairs. Other useful feature to distinguish them is their overall shape: centipedes tend to have flattened agile bodies, while millipedes have a more worm-like look.

Just to finish this whole Biology lesson, the agile serapedes are clearly related to the centipedes: they have a flattened body, few legs and a single pair of legs per body segment. We already knew that, of course, and now we can proceed to analyze its features and abilities.

GIGANTIC SIZE

Among the extant myriapod species, the largest one is called the "Peruvian giant yellow-leg centipede" or "Amazonian giant centipede"; its scientific name is *Scolopendra gigantea*. It lives in South America (not in Peru, despite its common name), in Colombia, Venezuela, Aruba and Curaçao, and may reach up to 30 cm in length (Shelley & Kisser, 2000). Although this is

very large for a centipede, it is nowhere close to the serapede.

However, as alluded to above, there is a fifth class of myriapods, called Arthropleuridea. This class is today completely extinct, meaning it is known only from fossils. One genus of this class is called *Arthropleura*, which encompasses five species. Based on the fossil record, we know that species of *Arthropleura* could reach up to 2.5 m in length (Fig. 3). Therefore, it is not only the largest known centipede, but the very largest land invertebrate. (The largest invertebrate overall is the giant squid *Architeuthis*, which may reach 18 m in length due to its long tentacles; Salvador & Tomotani, 2014.).



Figure 3. Reconstruction of the fossil giant myriapod *Arthropleura armata*. (Image from Sailko, 2012, Wikimedia Commons.)

The giant size of these fossil species has to do with their respiration. Myriapods and insects have a tracheal respiratory system, which is independent of the circulatory system. This means that the tracheas deliver air directly to the muscles, tissues and organs. These animals nowadays are restricted in size because of this type of respiratory system. *Arthropleura* species, however, lived in the Carboniferous

Period (359 to 290 million years ago), when oxygen concentration in the planet's atmosphere reached 35% (Dudley, 1998). That is a lot compared to today's oxygen concentration of 20.9%. So much oxygen on the atmosphere allowed for a more efficient tracheal respiration and thus, for gigantic sizes.

Gigantism is also found in other animal groups during the Carboniferous, such as amphibians (who are greatly dependable on cutaneous respiration), arachnids and insects. The extinct insect order called Meganisoptera deserves a little more attention. They are related to modern dragonflies (order Odonata) and, to prove they are more awesome than their living relatives, they are known as "griffinflies". Species of the griffinfly genus *Meganeura* could reach up to 70 cm of wingspan (Grimaldi & Engel, 2005).

So, for serapedes to achieve a gigantic size, the atmosphere of the planet Sera would have to be very rich in oxygen, much like that of our own planet's during the Carboniferous Period. If Sera has such high levels of oxygen, this could also explain the gigantic size of the muscles of the human characters in Gears of War. Really, just take a look at Cole, for instance (Fig. 4).

BODY ARMOR

As remarked before, serapedes have a bulletproof exoskeleton. We are told that a serapede "protects itself from victims with its plated back, making it vulnerable only to shots from behind; to totally exterminate the bug, humans have to shoot it apart one abdomen [sic; abdominal segment] at a time" (Gearspedia, 2015). That means the serapede's only vulnerable point is their "tail" segment

(last abdominal segment), in a classic example of video-game convenience.

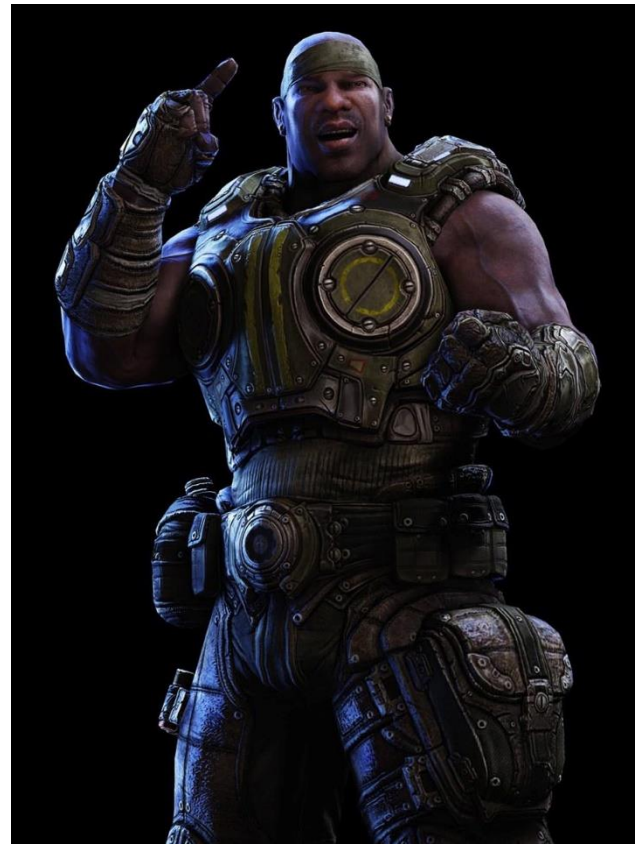


Figure 4. Pvt. Augustus Cole, a.k.a. "the Cole Train" (original model from the game).

The exoskeleton of all living arthropods is made of chitin, which is a modified polysaccharide derivative of glucose. It is mixed up with a protein matrix of sclerotin, which makes the exoskeleton hard but flexible. Crustaceans (including terrestrial forms) are the only living arthropods which can have mineral calcium carbonate (and sometimes also calcium phosphate) in their exoskeletons, making it even harder and simultaneously "cheaper" to produce (Vincent, 1990; Wilmot, 1990; Cohen, 2005).

But in terms of exoskeleton mineralization, no living arthropod can beat the fossil trilobites

(Fig. 5). Their carapace was made up of small amounts of chitin and protein and a comparatively huge amount of calcium carbonate (calcite) and calcium phosphate (Wilmot, 1990; Fortey, 2001). The trilobites' body armor would not only be resistant to cracking, but also (due to its protein matrix) would slow down the progress of fractures (Wilmot, 1990). But even with such amazing armor, there were predators going after them (their bellies were soft, after all). So, if the trilobite was injured and survived, it could heal its carapace, leaving a scar behind (Pratt, 1998).



Figure 5. The trilobite *Elrathia kingii* (ca. 40 cm in length), from the Middle Cambrian of Utah. (Photo by John Alan Elson, 2009; image modified from Wikimedia Commons.)

Trilobites could grow to large sizes. The largest one, *Isotelus rex*, from the Ordovician of Canada (roughly 460 million years ago), could reach over 70 cm in body length (Rudkin et al., 2003). Of course, all trilobites are marine creatures and their heavy carapace was mostly supported by the surrounding water. Carrying such a heavy armor on land, as the serapede does, would be problematic. There is no land trilobite we know of, but there is an animal group with calcium carbonate armor and species living both underwater and on land: the snails.

Snails are mollusks (phylum Mollusca) and are the second most diverse group of animals after the arthropods. They have a soft body, but are protected by beautiful shells made of a matrix of chitin and the protein conchiolin, hardened by a generous amount of calcium carbonate. Marine snails can also achieve very large sizes: the record-holding species, at 90 cm of shell length, are the extant *Syrinx aruanus* (also known as “Australian trumpet”) and the fossil *Campanile giganteum*, from the Eocene of France (McClain, 2014). A trilobite carapace was usually rather thin, but a marine snail's shell can be really thick and heavy (the shell of *Syrinx aruanus* can weight nearly 2 kg).

As already remarked, living underwater facilitates carrying such heavy shells. A land snail, on the other hand, would never be able to hold up and carry a shell weighting a few kilograms. The largest land snail species is the fossil *Pebasiconcha immanis*, from the Miocene of Colombia and Peru; its shell reaches up “only” to 26 cm in length (Wesselingh & Gittenberger, 1999).

In conclusion, a marine version of the serapede could have a very tough calcified “bulletproof” trilobite-like armor, but the regular terrestrial serapede would definitely not be able to carry it. Finally, the carapace of the serapede is said to be “steel-like” (Gearspedia, 2015) and we can see it is rather shiny and metallic (Fig. 1). There is only a single living animal known to have an exoskeleton made of metal and, once again, it’s a snail.

Chrysomallon squamiferum (Fig. 6), also known as the “scaly-foot gastropod” (although I personally prefer the name “iron snail”), lives around deep-sea hydrothermal vents of the Indian Ocean (Chen et al., 2015). The snail’s soft body is covered in iron spikes and, more importantly, the outer layer of its shell is made of iron sulphides (mainly the minerals greigite and pyrite). The remaining shell layers are made of calcium carbonate and proteins, as usual. This is an actual armor and, of course, the USA military are already funding research to discover how this shell actually works (Yao et al., 2010).



Figure 6. *Chrysomallon squamiferum*; shell width of ca. 4 cm. (Photo by David Shale; reproduced from Chen et al., 2015.)

So, could a serapede (or any myriapod, for that matter) have an iron-plated carapace? Well, no. Besides the weight problem discussed above, *Chrysomallon squamiferum* gathers its iron from the hot vents. (Curiously, a separate population of *Chrysomallon squamiferum* that lives near iron-poor vents have completely iron-free white shells and spikes.) Serapedes/centipedes would be hard-pressed to find an environment on land with iron sulphides available in a similar way. Other iron sulphide-rich environments would still be aquatic, namely the bottom of some mangroves, swamps and estuaries (Thomas et al., 2003). But there would be three problems: (1) there are no aquatic myriapods; (2) the iron compounds oxidize quickly when exposed to the atmospheric oxygen; (3) even if a myriapod managed to live in such environment and use its iron compounds, it probably would not be enough to cover its entire carapace (the hot vents where the iron snail lives release a much higher amount of these compounds).

ACID SPRAY

Centipedes are mainly carnivorous, and very efficient hunters to boot. They rely on a pair of appendages near their mouth to inject venom on their prey. These appendages look like pincers and are called “forcipules”; the venom can either paralyze or outright kill the prey (Lewis, 1981). It is a very big letdown that the Carboniferous giant *Arthropleura* apparently were not predators; instead, they would have been herbivorous, feeding on pteridophytes (Scott et al., 1985). But do not fret, centipede venom is not lethal for humans (Bush et al, 2001).

Serapedes, on the other hand, can be very lethal indeed. Instead of delivering the venom through their forcipules (which they do seem to have; see Fig. 1), serapedes can spit a poisonous spray. In a very “Dungeons & Dragonese” way, such spray is not only poisonous, but also acidic.



Figure 7. The bombardier beetle (*Stenaptinus insignis*) in the middle of some serious bombarding action. By the way, they can precisely aim the spray. (Image reproduced from Eisner & Aneshansley, 1999.)

No living centipede (or myriapod) can shoot an acid spray. Some insects, however, can. For instance, wood ants (of the *Formica rufa* group) can spray formic acid from their abdomen up to 12 cm away (Löfqvist, 1977). The devil-rider stick insects (genus *Anisomorpha*) can shoot terpenes from glands on their thorax (Meinwald et al., 1962). Last but not least, the beetle family Carabidae have a plethora of noxious sprays (Moore, 1979). Oogpister beetles (genus *Anthia*), for instance, can spray formic acid from their abdomen; they supposedly get their acid by eating ants. The

more famous bombardier beetles (e.g., the genera *Brachinus* and *Stenaptinus*) can shoot a spray made up of two substances (hydroquinone and hydrogen peroxide) stored in two distinct compartments in their abdomen (Fig. 7). When these substances combine, an exothermic reaction occurs, generating so much heat that it brings the beetle’s spray to almost 100 °C (Aneshansley et al., 1969; Eisner & Aneshansley, 1999).

If such ability can evolve multiple times in separate insect lineages, it is not so farfetched that it could also arise in centipedes. Or, more specifically, in serapedes. If the combination “acid + venom” seems too much weaponry for a single animal, please remember that each species of *Conus* snails has a cocktail made of up to 200 different toxins in order to daze, confuse, paralyze, shock and kill their prey (Oliveira & Teichert, 2007; Scales, 2015).

ELECTRIC DISCHARGE

The final ability of the serapede is the electrical discharge (the “shoot lightning” stuff). Serapedes are clearly terrestrial animals, while bioelectrogenesis (the capacity of living organisms to generate electricity) is only known in aquatic animals, such as the electric eels and other types of fish. These animals use electricity to stun their prey, thwart aggressors or communicate with conspecifics. Most of them (as well as other aquatic animals, such as rays, sharks and platypuses) also have the ability to detect electrical stimuli, called electroreception. Electroreception is known among a few terrestrial animals: the echidna (which descend from an aquatic ancestor, in

any case) and some fully terrestrial species of insects.

As said before, no land animal can produce an electrical discharge, but there is a single curious case of electricity generation: the Oriental hornet (*Vespa orientalis*; Fig. 8). This insect actually converts sunlight into electricity. However, it is not yet clearly known how the hornets use this on their daily lives (Ishay et al., 1992), although some researchers have suggested that it might give them extra energy for either flying or digging (Ishay, 2004; Plotkin et al., 2010). If this is the case, these insects are effectively partly solar-powered.



Figure 8. The Oriental hornet. (Image reproduced from BioLib.cz.)

Insects and myriapods, as already explained above, are related groups and thus share many physiological traits. However, given that electricity generation in terrestrial insects is extremely rare (we only know the Oriental hornet from a million of described insect species), we should not expect that such trait would evolve easily in myriapods. Regardless, a huge and heavily-armored creature such as a serapede would indeed benefit from the extra

energy of solar-powered electricity. Too bad they live underground, though, in the tunnels of the Locust Horde.

Leaving the realm of Biology and entering the mythological domain, there is one legendary beast that uses electricity as a weapon and is not aquatic. We will explore it below.

ORIGINS

The Mongolian Death Worm (seriously, this is its actual name; it is also known as “olgoi-khorkhoi” or “large intestine worm”, which doesn’t make it any better) is a mythological being that supposedly inhabits the Gobi Desert. The beast is described as a huge (0.5 to 1.5 meters long) earthworm-like (or intestine-like, if you will) creature, as wide as a man’s arm and bright red in color (Fig. 9). It is said it can use either acid or electricity as weapons. People in Mongolia (and so-called “cryptozoologists” worldwide) still believe in this very D&D-like monster. (By the way, it is incredible that such a B movie beast like this worm hasn’t found its way into the D&D Monster Manual yet.)



Figure 9. An interpretation of the Mongolian Death Worm. (Illustration by Pieter Dirkx; image reproduced from Wikimedia Commons.)

According to the Gearspedia (2015), the Death Worm is the possible inspiration for the Serapede. This is speculation due to the monster's unusual combination of acid and electricity. We lack any actual statement of the games' developers to say for certain (they did not answer me, by the way). However, the serapede's visual (and name) is clearly based on real centipedes. So, rather than being a "Heavy Metal" incarnation of the Mongolian Worm, the serapede seems to be basically a centipede given superpowers.

CONCLUSION

So, to wrap things up, a serapede is actually partly biologically possible. Its huge size is feasible, but should come along with an increased oxygen concentration in the atmosphere. The poison/acid spray is rather common in arthropods, so it should not be a problem either. Its bulletproof armor, however, would be way too heavy a burden to carry on land and iron-plating on land is simply impossible. Finally, electricity-generating capabilities are extremely unlikely on land, given that it is known only in a single species.

Despite looking like B movie stuff, it should be granted that serapedes are much closer to biological reality than many supposedly "scientifically accurate" Sci-Fi out there. In any event, regardless of their feasibility, serapedes are one of the most awesome monsters in recent gaming history. Better yet, it is a playable monster, so we can use it to wreak havoc amidst the humans' ranks.

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Squids, octopuses and lots of ink

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Splatoon was recently released (second quarter of 2015) for the Wii U, receiving a warm welcome by Nintendo fans (it's nigh unthinkable for the company to launch a new IP like this) and generating a flood of fan art on the Internet. The game is a third-person shooter with ink instead of bullets. It features two races, inklings (the playable one) and octarians (the enemies), and revolves around the fierce dispute against each other. (In multiplayer though, its inkling against inkling.) Inklings and octarians (especially the elite soldiers called "octolings") are based, respectively, on squids and octopuses (Fig. 1), two of the most awesome kinds of animals out there.

These animals are mollusks, and, more specifically, cephalopods. The mollusks are the second largest animal group on Earth (after the arthropods, of course) and includes gastropods (snails and slugs), bivalves (clams, mussels and oysters), cephalopods (we'll come back to them soon) and the little known scaphopods (tusk shells), monoplacophorans, aplacophorans, polyplacophorans (chitons) and some fossil oddities. For those who remember their biological classification, we can put it like this:

the class Cephalopoda belongs to the phylum Mollusca.

Cephalopoda is a group that contains a vast array of marine animals. Besides squids and octopuses, it counts with cuttlefish, nautiloids and the fossil belemnites and ammonoids. Today, cephalopods are found everywhere in the sea, from the polar regions to the tropics and from the surface to depths over 5,000 m. There are over 800 known living species of cephalopods, but the fossil record counts with more than 17,000 species (Boyle & Rodhouse, 2005; Rosenberg, 2014).

The class appeared over 450 million years ago during the late Cambrian, the first period of the Paleozoic era (Boyle & Rodhouse, 2005; Nishiguchi & Mapes, 2008). Cephalopods enjoyed a high amount of diversity during the Paleozoic and Mesozoic eras, with hundreds of species of nautiloids and ammonoids (Monks & Palmer, 2002). Most of these forms, however, did not survive to this day. Ammonoids and belemnites were completely extinguished and today we have just a handful of *Nautilus* species and the group consisting of cuttlefish, squids and octopuses. This group is a latecomer in cephalopod history: it appeared only during the

Mesozoic, although some late Paleozoic fossils have tentatively been classified as squids (Boyle & Rodhouse, 2005; Nishiguchi & Mapes, 2008).

OK, so we can all see that Splatoon is a cephalopod-themed game. But before we can say something about the critters starring in Splatoon, we must first clear some Biology stuff. The foremost of these issues is: there is a long-lived and persistent confusion in popular

knowledge, art and fiction, regarding squids and octopuses. People just do not seem to know which is which. Many biologists have bemoaned this and tried to set things right in popular works for quite a while (e.g., Lee, 1883; Salvador & Tomotani, 2014). Since these animals are our main theme here, we feel obliged to explain what, after all, are the differences between a squid and an octopus.



Figure 1. Top left: an inkling girl in human form (original model from the game). Top right: *Loligo vulgaris*, an example of a squid species (photo by Hans Hillewaert, 2005; image modified from Wikimedia Commons). Bottom left: an elite octarian soldier, a.k.a. octoling (original artwork from the game). Bottom right: *Octopus rubescens*, an example of an octopus species (photo by Taollan82, 2007; image modified from Wikimedia Commons).

SQUID OR OCTOPUS?

For the uninitiated (*i.e.*, those whose sad childhoods did not include wildlife documentaries and visits to zoos and/or aquariums), squids and octopuses look the same. However, if one pays attention and carefully compare one to the other, many differences start to pop up. The first one is the overall shape of their bodies (Fig. 2): squids

usually have a bullet-like shape and a more hydrodynamic body, with a pair of fins on their extremity; octopuses have a globose body, which is capable of some serious shape-changing. These animals' shapes are linked to their way of life: squids are active swimmers, while octopuses live on the sea floor, hiding under rocks or inside burrows.

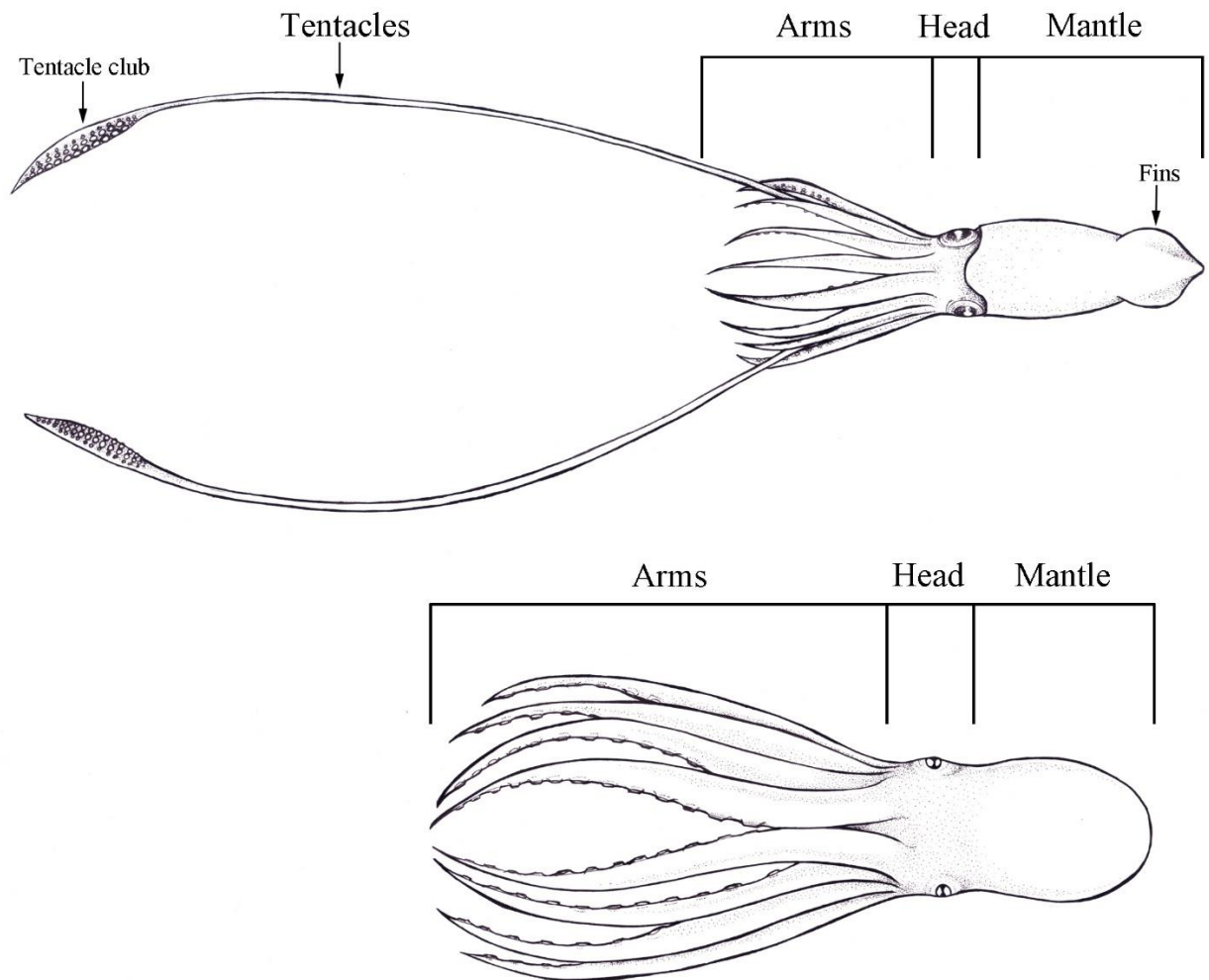


Figure 2. Diagrams of a squid (above) and an octopus (below), accompanied by the proper scientific terminology of their body parts. Image reproduced from Salvador & Tomotani (2014).

Nevertheless, there is an even more striking difference (Fig. 2): an octopus has only eight arms, while a squid has eight arms and two

tentacles (readily identifiable: they are more slender and usually longer than the arms).

The difference in meaning between “arm” and “tentacle” is crucial, but these words unfortunately are used interchangeably in popular writing. The arms of both squids and octopuses are covered with suction cups (or suckers) on their inner surface. (These suckers are sessile in octopuses, but squids have stalked mobile ones.) The tentacles, present only in squids, are smooth (*i.e.*, without suckers) along almost their entire length; only the tentacle’s tip (called “club”) has suckers (Fig. 2).

Despite the popular confusion of squid/octopus and arm/tentacle, it seems Splatoon’s developers took care to be as accurate as they could with their cartoonish squids. The Inklings, when in squid form, have the correct number of arms, with the two tentacles clearly differentiated (Figs. 4, 9). Incredibly, this is also true for an Inkling in human form and the game’s official Japanese Twitter took some pains to show it is so (Fig. 3).

Finally, the last main difference lies inside their bodies. As anyone can tell, the most obvious feature of mollusks is their shells; just think of a snail or a clam and you immediately picture their shells. However, most living cephalopods do not have shells (nautilus and the tiny *Spirula spirula* are the exception).

Squids have only a remnant of a shell called a “pen” (or gladius) that serves as a skeletal support for their bodies. Octopuses, however, have absolutely no shell whatsoever. In all other respects, squids and octopuses are very similar, since they are both cephalopods. So now we will dabble a little in cephalopod anatomy, because we will need some concepts to discuss other features from Splatoon.

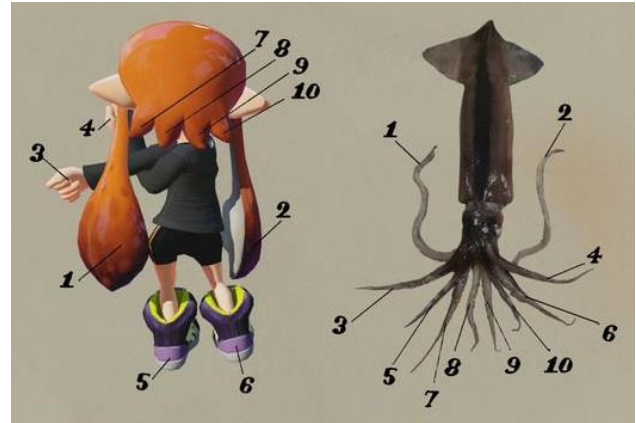


Figure 3. Diagram showing the correspondence of arms between an Inkling (in human form) and a real squid. The tentacles are numbered as 1 and 2, while the remaining arms are numbered 3 to 10. Image taken from Splatoon’s official Japanese Twitter (<https://twitter.com/SplatoonJP>).

CEPHALOPOD ANATOMY

Before moving on to other topics, we have one final note on tentacles. The Inklings’ tentacles, more specifically the club on the tip of each tentacle, are smaller than the Inklings’ girl’s is. The official artwork seems to suggest that this is the case (Fig. 4) and this was confirmed in-game at least for the Inklings in human form (it was difficult to compare squid forms due to all the shooting). Moreover, this is clearly seen on the Amiibo figures, where the boy’s tentacle clubs are about half the size of the girl’s (Fig. 5).

Sexual dimorphism (*i.e.*, male and female of the same species looking different) is rather common in cephalopods and the difference usually lies on overall body size: in some species the males are larger while in others the females are the larger ones (Boyle & Rodhouse, 2005). However, differences in the size of tentacles and clubs seem to be rare, known only from cuttlefish (Bello & Piscitelli, 2000). Perhaps this matter was not investigated enough in other species, meaning that differences in tentacle or

club size could be more widespread in cephalopods. In any case, Bello & Piscitelli (2000) studied the species *Sepia orbignyana*, in which the females are larger than the males. They discovered that the female's tentacle clubs were also proportionately larger (in relation to the body) than the male's. They discuss that this feature is linked to feeding: cuttlefish use their tentacles to capture prey and, since females are larger and need more food, individuals with larger clubs have an advantage (they are able to capture larger prey) and were thus selected through the species' evolutionary history.



Figure 4. Inkling girl (top) and boy (bottom) in both human and squid forms. (Original artwork from the game.)



Figure 5. Photos of the Amiibo figures of the inkling girl (left) and boy (right) in human form. Note how the girl's tentacles are much larger than the boy's.

Now, moving on with the anatomy. The mouth of a cephalopod is located in the middle of the circle formed by the arms. It contains a pair of powerful chitinous mandibles, which together are called a “beak” due to their resemblance to a parrot's beak (Fig. 6).

Inside the mouth lies the radula, a rasping tongue-shaped structure equipped with many rows of small chitinous teeth (Fig. 7). The animals use the radula to “scratch” their food and pluck small portions of it. (Note that the radula is a feature common to all mollusks, with the notable exception of the bivalves, which are filter feeders and have lost the radula in the course of evolution.) In *Splatoon*, the designers' care is shown here once more: inklings in human form have pointed teeth to emulate the sharp beaks of squids.

Cephalopods breathe through gills located inside the mantle cavity (Fig. 8). The water enters this cavity through apertures on the mantle edge close to the head and brings dissolved oxygen to the gills. The water is then expelled from the cavity by a structure called

“funnel”. The funnel is also capable of expelling a powerful gush of water, which is responsible

for the fast jet propulsion movement of cephalopods.

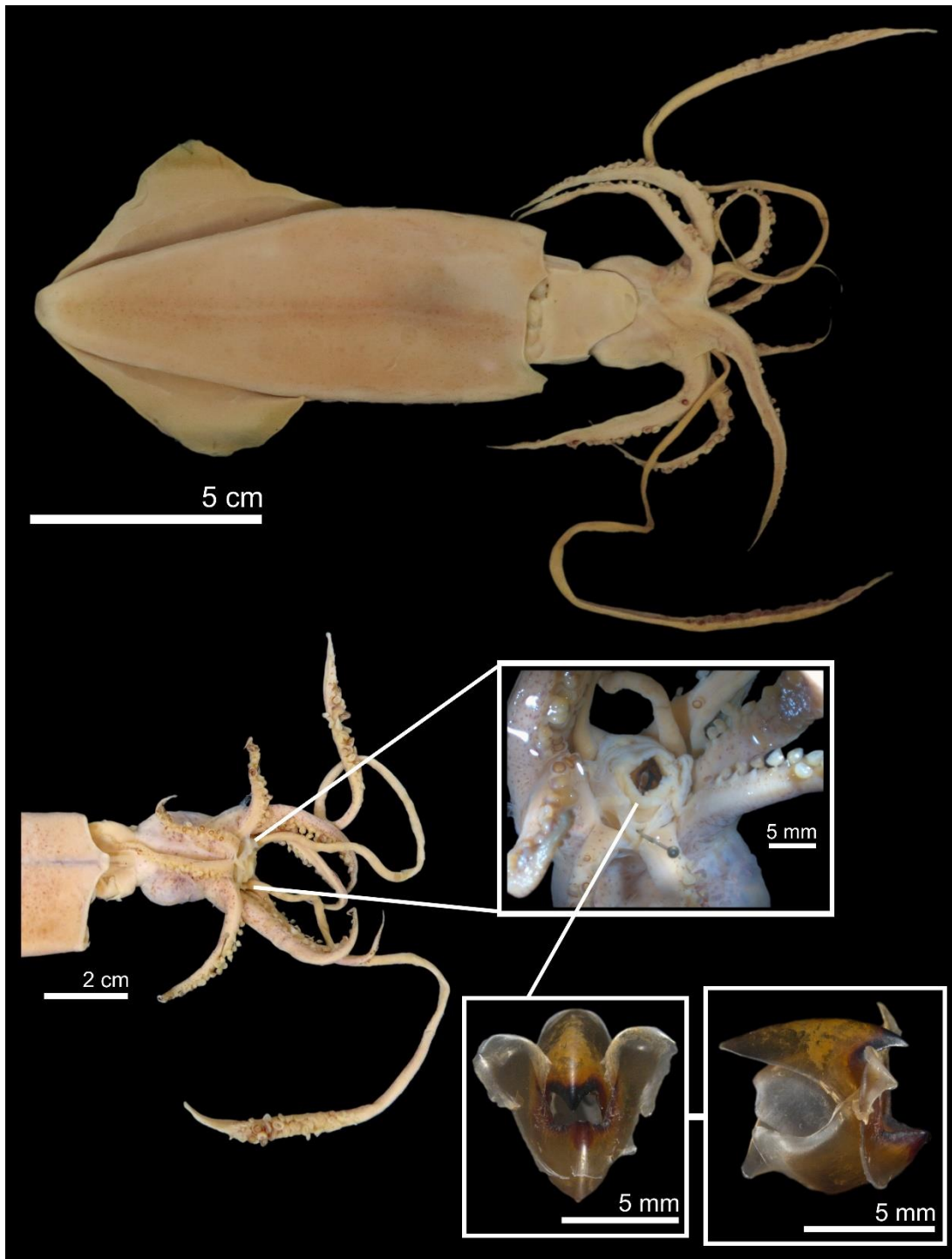


Figure 6. A (dead) specimen of the squid species *Loligo sanpaulensis*. The top image show the whole body of the animal. The bottom left image shows the mouth region on the center of the ring of arms and tentacles. The bottom right inset shows a close-up of the mouth, with the beak barely visible on its center. The last two insets on the very bottom right show the beak (removed from the specimen) in frontal and lateral views.

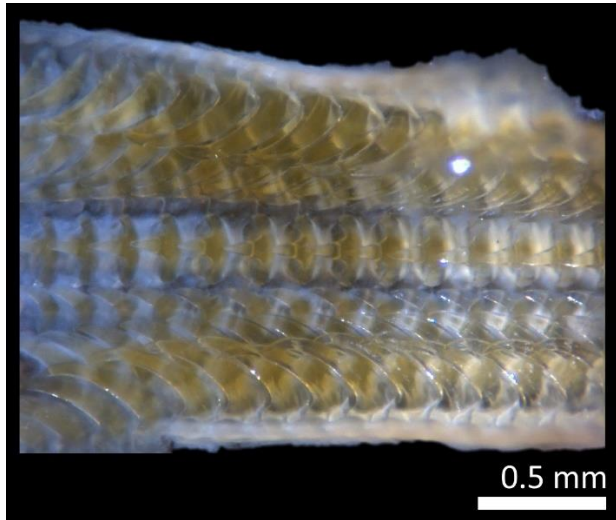


Figure 7. The radula (removed from the specimen of Fig. 6), shown straightened out. Notice the neat rows of pointy little “teeth”.

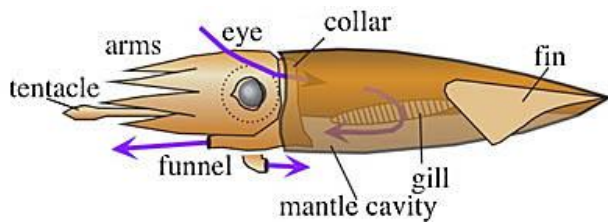


Figure 8. The arrows indicate the way in which water passes through the squid's body, entering the mantle cavity (shown in transparency), passing by the gills and exiting via funnel (shown in two positions, for forward and backwards movement). Image reproduced from Richard E. Young, 2000, *The Tree of Life Web Project* (Creative Commons Attribution Non Commercial License 3.0).

If inklings can leap very high from a pond of ink when in squid form, jet propulsion is the reason why. This might better be called “ink-jet-propulsion”, though (Fig. 9).

As a matter of fact, the funnel has an important role in the most characteristic aspect of cephalopod biology: inking. And this is what we will turn to now.



Figure 9. Inkling, in squid form, jumping propelled by its ink-jet-propulsion. (Original model from the game.)

INK

Inside the mantle cavity there is an organ known as “ink sac”, which, as the name implies, is a reservoir of ink. The animals can expel this ink through the funnel and they do this in two very ninja-like manners: as clouds or as pseudomorphs (Derby, 2007). Ink clouds are pretty straightforward, functioning as a smoke screen to allow the cephalopod to escape (Fig. 10); although some recent observations show that they can also be used to confuse and sneak attack prey (Sato et al., 2016). Pseudomorphs (meaning “false-shapes”) are more curious things. They are made of ink and mucus and appear as a well-defined and stable form (maintaining its physical integrity for a while after it is released). These pseudomorphs can be almost as large as the animal releasing them. It is thought they serve as a decoy, a fake double of the cephalopod which will distract the predator and allow it to escape unharmed. Finally, cephalopods’ ink might also contain organic compounds that act either as toxins to deter or damage enemies or as signals to warn

conspecifics (members of the same species) of any danger (Derby, 2007).



Figure 10. Ink cloud created by a Humboldt squid, *Dosidicus gigas*. Image reproduced from Bush & Robinson (2007).

In Splatoon, the main purpose of the ink is, well, to ink stuff. Inklings shoot ink through guns (not funnels), hoping to beat their opponents senseless (“splat” them, as the game puts it) and to ink the largest portion of the battlefield to achieve victory (Fig. 11).



Figure 11. A chaotically inked Splatoon battlefield. (Screenshot from the game.)

Inkling’s ink is the same color as their body (Fig. 12). True cephalopods’ ink is always dark (due to its main constituent, melanin), of course, but we can all agree that different colors of ink was a fair gameplay necessity. And, speaking of body color, cephalopods are the most colorful animals out there (sorry, birds).



Figure 12. An inkling’s ink is always the same color as its body. (Original models from the game.)

COLORFUL AND SMART CREATURES

Cephalopods are so colorful because they can actually change their body color and also their color patterns. They have specialized cells in their skin called chromatophores, which enable them to instantly change color to camouflage themselves (either to evade predators or to ambush prey; Fig. 13), to communicate with conspecifics, or to ward off predators (Hanlon & Messenger, 1996; Hanlon, 2007; Mäthger et al., 2012). Some scientists even argue that cephalopods can produce waves of changing color patterns to mesmerize prey and make them easier to catch (e.g., Mauris, 1989; Mather

& Mather, 2006), but this remains scarcely proved.

Doing justice to cephalopod coloration, inklings come in many colors: turquoise, lime green, purple, pink, orange and blue. And they change colors basically for each battle.



Figure 13. Photo sequence showing an octopus de-camouflaging itself. Image reproduced from Hanlon (2007).

Box 1. Ink and slime

Inklings can only move freely on ink of the same color as theirs; they get stuck in other colors of ink (*i.e.*, those produced by their opponents). Cephalopods, of course, have no such restriction of movement, but another kind of mollusk does. Land snails and slugs produce a mucous slime in order to move; they actually “glide” on top of it. Was this an intentional decision by the game developers, based on actual knowledge of mollusks? Or was this merely a gameplay choice that resulted in a nice molluscan coincidence?



A land snail leaving a silvery slime trail on its wake. Photo by “snail ho”, 2007; image modified from Wikimedia Commons.

We mentioned above that cephalopods can communicate with each other by changing their color pattern (Shashar et al., 1996; Mäthger et al., 2009). This kind of communication can only

work if the animals using them possess a high degree of intelligence. And indeed they do. Cephalopods can solve puzzles, cause all sort of embarrassments for caretakers in aquariums

and zoos, and even use tools (Mather, 2008; Finn et al., 2009). Their nervous system is the most complex among invertebrates and, actually, their brain-to-body-mass ratio falls between those of endothermic (birds and mammals) and ectothermic (all the others) vertebrates (Nixon & Young, 2003).

In Splatoon, the inklings and octarians are clearly intelligent enough to build cities and weapons. One of the Sunken Scrolls (a kind of game collectible that tells more about the backstory) reveals that the two races evolved when rising sea levels (yes, that's Global Warming) wiped out humans and allowed sea creatures to take over (Splatoon Wiki, 2016).

SPECIES IDENTIFICATION

Now, after such a long immersion in cephalopod biology, it's past time we try to identify which species exactly (if any) served as the basis for Splatoon's inklings. (Unfortunately, octarians have a way too generic octopus design to allow some proper identification.)

The game's developers have not stated which squid species (or number of species) they used as basis for the inklings. However, gamers on the Internet have referred to the Humboldt squid (Splatoon Wiki, 2016) or to the Japanese flying squid (on some forums). The Humboldt squid (Fig. 14), *Dosidicus gigas*, in the first place, is not a Japanese species (we assume Japanese game developers basically only use Japanese stuff for their games; see the majority of critters in Pokémon, for instance). The Humboldt squid is found on the Pacific coast of the Americas (Zeidberg & Robinson, 2007). As such, the Japanese flying squid (Fig. 14), *Todarodes pacificus*, would seem a good choice.

The Japanese flying squid belongs to the same family (Ommastrephidae) as the Humboldt squid. The squids in this family, as their common names imply, use jet propulsion to "fly" above the sea surface, covering a few tens of meters in each jump. This behavior is thought to be related to predator avoidance or to save energy as the squids migrate across vast ranges. It could be safely assumed that the jet-propelled jumps of the inklings in Splatoon (Fig. 9) were based on squids from this family. As a matter of fact, other flying squids of the family Ommastrephidae can be found in Japanese waters, such as the "neon flying squid", *Ommastrephes bartramii*.

Ommastrephidae species also have a shape similar to the inkling's squid form (Fig. 14), with large fins forming a triangle on the tip of the body, a tubular section of the mantle leading from it to the head and small arms. As such, it is safe to assume that this family of squids served as inspiration for both behavior and design of the inklings. However, the tubular section in the inkling is where the eyes are located and could thus be interpreted as the whole head. As such, there is another possible species that might have influenced the inkling's design: the diamond squid (Fig. 14), *Thysanoteuthis rhombus* (family Thysanoteuthidae). As its name implies, the fins give the animal a diamond shape and extend all the way to its head (as the inkling's head seem to be immediately below the fins). Moreover, it has short and strong arms and tentacles, like the inklings. This species can be found worldwide, but is an important catch for the Japanese fishing industry (Bower & Miyahara, 2005) and it is to this topic that we will turn next.

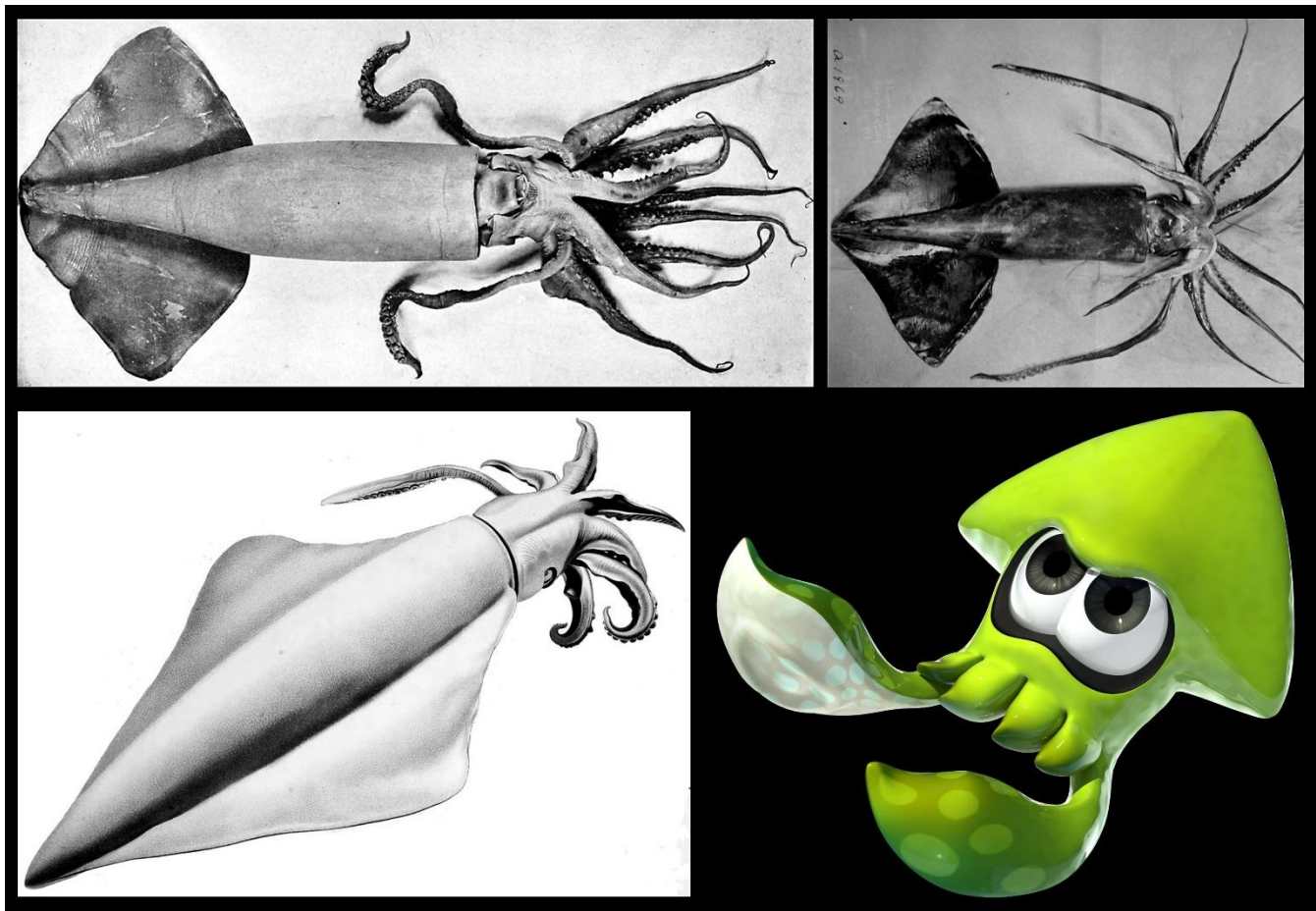


Figure 14. Top left: *Dosidicus gigas*, the Humboldt squid (image modified from Wikimedia Commons). Top right: *Todarodes pacificus*, the Japanese flying squid (image modified from Wikimedia Commons). Bottom left: *Thysanoteuthis rhombus*, the diamond squid (image modified from Wikimedia Commons). Bottom right: inking in squid form (original model from the game).

THE FISHING INDUSTRY

It is very common for gaming developers to come up with jokes for April Fools' and last year even Nintendo joined in. A post on Splatoon's official Tumblr page read: "So... *this whole time I thought 'Splatoon' was going to be the name of the game, but it's not. Splatoon is actually a hot new snack that's coming out in May! You gotta be squiddin' me! Now you can have your squid and eat it too! Unless you're a squid, then... maybe don't because that's weird and kinda creepy. Maybe just eat a quesadilla.*" A photo of

the supposed snack's package (Fig. 15) accompanied the post.

While it may be a cute April Fools' joke (the Japanese seem to love these strange snacks), it brings up a very serious question: Japan's destructive fishing practices. As remarked above, the diamond squid is a very important species for the Japanese fishing industries, but the Ommastrephidae flying squids also consist in large portions of their catch (FAO, 2015a). As a matter of fact, all of these species are heavily exploited and the species are in steady decline

(Bower & Ichii, 2005; Bower & Miyahara, 2005; FAO, 2015a).

The loss of a single squid species may not seem much to most people. But when a species goes extinct, its absence may lead the whole ecosystem to a disastrous collapse. In the long run, the only thing we'll be eating from a barren sea will be jellyfish burgers. Japan's fishing industry is one of the most overexploiting in the world (Clover, 2004; Roberts, 2007; FAO, 2015b); besides, Japan is involved in a huge controversy regarding its whaling practice.



Figure 15. The April Fools' Splatoon snack. Image taken from Splatoon's official Tumblr (<http://splatoonus.tumblr.com/>).

Nobody is expecting people to just stop fishing; the sea is an amazing resource to feed the increasing number of humans on the planet.

Moreover, seafood is a staple of Japanese cuisine. Even so, the fisheries could do better with some planning, to avoid species and ecosystems collapses. Some restrictions, accompanied by proper regulation, should be put in place. For us consumers, Clover (2004) offers advice on how to make a difference, buying only lawfully catch seafood (identified by seals of quality or similar markings) and always inquiring where said seafood comes from (to avoid buying something from threatened areas).

Box 2. Mario's Famous Squid

The inklings' squid form is also reminiscent of another famous Nintendo squid: Blooper. Everyone should be familiar with this recurrent antagonist from the Mario series, which is present in almost every underwater stage across several Mario titles (Cavallari, 2015). Despite Blooper's simple design, it can be safely recognized as a squid (Cavallari, 2015) and it is curiously very similar to Splatoon's inkling. However, according to the game's developers, they did not use Blooper as a base for the inkling's squid form design (Splatoon Wiki, 2016).



Inkling in squid form (left) and Blooper (right). Artwork by CutyAries (<http://cutyaries.deviantart.com/>); image is a courtesy of the artist.

CEPHALOPOD CONSERVATION

Typically, invertebrates are not a priority in conservation efforts, since they are usually faced with lots of antipathy. As such, the role of flagship species for raising people's awareness about biodiversity loss and the dire need of conservation measures is often reserved for mammals and birds (and the eventual tiny cute frog). Cephalopods usually do not get much attention in conservation efforts, but they do have some charismatic species that can serve such purpose (and should definitely be used). Among the squids, the semi-mythic giant squid *Architeuthis* sp., the animal who originated the legend of the Kraken, is the most obvious choice (Guerra et al., 2011; Salvador & Tomotani, 2014). Among the octopuses, everyone should remember Paul, the "clairvoyant" cephalopod who predicted the results of the 2010 FIFA World Cup, and the little octopus *Opisthoteuthis* sp. that made the news everywhere this year just for being so damn adorable (Fig. 16).



Figure 16. *Opisthoteuthis* sp. Screenshot taken from the YouTube video by SciFry (15/Jun/2015): <https://www.youtube.com/watch?v=vv7Dfebpl7E>.

There is no doubt that the media and works of fiction can help in environmental education and in raising ecological awareness. (It can work against it too, like when the movie *Jaws* started a shark-killing frenzy.) We believe that games can and should have a much more prominent role in these efforts. This is especially true for a game like *Splatoon*, which is more children-friendly. After all, we have to teach this ecological awareness to children (adults are already too narrow-minded to listen).

For instance, the game *Never Alone* (released November 2014) has its story and setting based on Inuit folklore and culture. As the player progresses in the game and encounters different things, he/she unlocks a series of short documentaries which explain facets of the Inuit culture, their arctic environment and arctic animals. This shows that games can both entertain and actually teach something of value.

A different (and more direct) kind of approach was taken by Rovio Entertainment Ltd., house of the famous *Angry Birds* franchise. The company joined forces with BirdLife International to fight against the extinction of the wondrous South Pacific birds. Unfortunately, their crowdfunding campaign reached only about half of its US\$ 150,000 target in donations (Save the Birds of the Pacific, 2015). Just for comparison, games overhyped by the media (e.g., *Shenmue*) were meanwhile gathering over 6 million dollars on Kickstarter; so gamers do have money to spend.

Could *Splatoon* be used for educating players and raising environmental awareness? Yes, it could. Could Nintendo do the same as Rovio did and join some cephalopod

conservation effort? Definitely. Will this ever happen? Likely not; as explained above, Japan is too busy eating all squids in the Pacific Ocean.

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- MATERIAL ANALYZED**
- The material analyzed for this study (i.e., the inkling Amiibo figures) is deposited in the private collection of one of the authors (R.B.S.), next to a Kirby and an Elite Stealth Elf.
- The squid specimen from Figs. 6 and 7 is deposited in the scientific collection of the Museu de Zoologia da Universidade de São Paulo (São Paulo, Brazil) under the record number MZSP 86430. No mollusks were harmed during this work.



The strongest starter Pokémon

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Earlier this year, an article entitled “*Which is The Most Offensively Powerful Starter Pokémon?*” (Codd, 2016) caused great controversy on the Internet among players and fans of the Pokémon franchise. This article compared the three classical starter Pokémon, based on the anime, and concluded that Charizard was the strongest one.

The present work aims to analyze and discuss the data presented by Codd (2016) regarding the following issues: (1) Does his anime-based data coincide with the game mechanics? (2) Can his study be applied to metagame prospects? (3) Is Charizard really the most “powerful” Pokémon in-game?

ABOUT POKÉMON

Pokémon™ is an entertainment franchise, created by Satoshi Tajiri in 1995, that started with video games, but now includes an anime, a trading card game, clothing and several other products. Needless to say, the main products of the franchise (the games and anime) caused a large impact in recent pop culture.

The first products to be released were the “twin games” Pokémon Red and Pokémon Green, in 1996 in Japan. These games were later (in 1998) released worldwide as the Red

and Blue versions for Nintendo’s Game Boy console. (As a side note, in celebration of its 20 years of existence, earlier this year the Pokémon Company released a website containing a timeline of their products).

On TV, Pokémon was first released in Japan in 1997 with the episode “*Pokémon – I Choose You*” (released in the United States only in 1998; Wikipedia, 2016), triggering wide public attention. The franchise is now successful worldwide, attracting millions of fans and players of all ages, ethnic groups and social classes, and the games are often regarded extremely seriously by the players.

CODD’S THEORY

Codd (2016) concluded in his article that Charizard (the last form of the starter Charmander) was the most powerful of the three initial options (the grass-type Bulbasaur, the fire-type Charmander and the water-type Squirtle; Fig. 1). To reach this conclusion, Codd based his work on “data” provided by the anime, specifically (for Charizard) in the episode “*Can’t beat the heat!*” (aired 17/Feb/2002), from which he estimated variables such as weight (body mass), height and width of the Pokémon. Through a series of

calculations, all very well-founded in Physics, Codd determined that the offensive power of Charizard is well ahead of its competitors.

Codd's calculations are in fact quite accurate and may be applicable **to the anime**. But it behooves us a little analysis regarding the applicability of his results **to the game**. At the very start of his article, Codd states:

*"At the start of each Pokémon **game**, the player is given a choice of starter Pokémon. The options are almost always a choice between a fire type, a water type and a grass type. In most ways the most iconic of the starter Pokémon across all Pokémon generations are the original three; Charmander, Squirtle and Bulbasaur, which will fully evolve into Charizard, Blastoise and Venusaur respectively."*

— Codd (2016: p. 1), my highlight

Therefore, the first sentence of this quotation makes it clear that the author refers to the games, with its challenging proposition of having to choose one of three possible options to continue. In the same paragraph Codd says:

*"Each of these Pokémon also have a signature move, one which is closely linked to them through the course of **the anime and the games**. For Charizard this is Flamethrower, for Blastoise this is Hydro Pump and for Venusaur this is Solar Beam."*

— Codd (2016: p. 1), my highlight

Thus, the author establishes an intrinsic connection between anime and game. From this point on, he starts his analysis based on the size and proportions of the starting Pokémon

gathered from the anime. Despite this, the authors surmises that his calculations may be applied to the game. The discordance between Codd's arguments and the games is based on a simple fact: he used estimates and variables that are not true (or accounted for) in the native mechanics of the game, being thus irrelevant in determining the offensive capability of a given Pokémon. In the game,

"Each Pokémon has six major Stats, which are as follows: HP, Attack, Defense, Special Attack, Special Defense and Speed. HP means 'Hit Points' and represents health ('amount of vitality') of a Pokémon. When it suffers damage, a numerical value is calculated by the game, and the result is subtracted from the current HP. When HP reaches zero, the Pokémon faints and is out of action."

— Vianna Sym (2015: p. 26), my translation

In the games, Pokémon are defined by certain features, among which are the above-mentioned Stats. Each Pokémon has a given number of points assigned differently to its Stats, making it tough, agile or strong. HP represents the Health Points (or Hit Points) of a Pokémon, and from the work of Codd (2016), it is understood that a Pokémon that is "powerful" is the one with the highest chances to take the opponent's HP down to 0 more effectively.

Thus, to estimate how powerful a Pokémon is, one should not base his/her calculations on features estimated from the anime, but rather analyze the Stats distribution of a given Pokémon as it appears in the game. This study takes into account the Stats of each of the starting Pokémon to more thoroughly analyze

how powerful each can become, that is, how much damage a Pokémon can cause in a battle.

CASE STUDY

Let's first set the game to be any of the so-called "Gen I" versions (Pokémon Red, Blue, Green or Yellow), released between 1996 and

1998. In these versions of the game, there were less Stats, only: HP, Attack, Defense, Special and Speed (also, there were no mega-evolutions). The distribution of stats between the starting Pokémon (in their last form) can be seen in Figure 1.

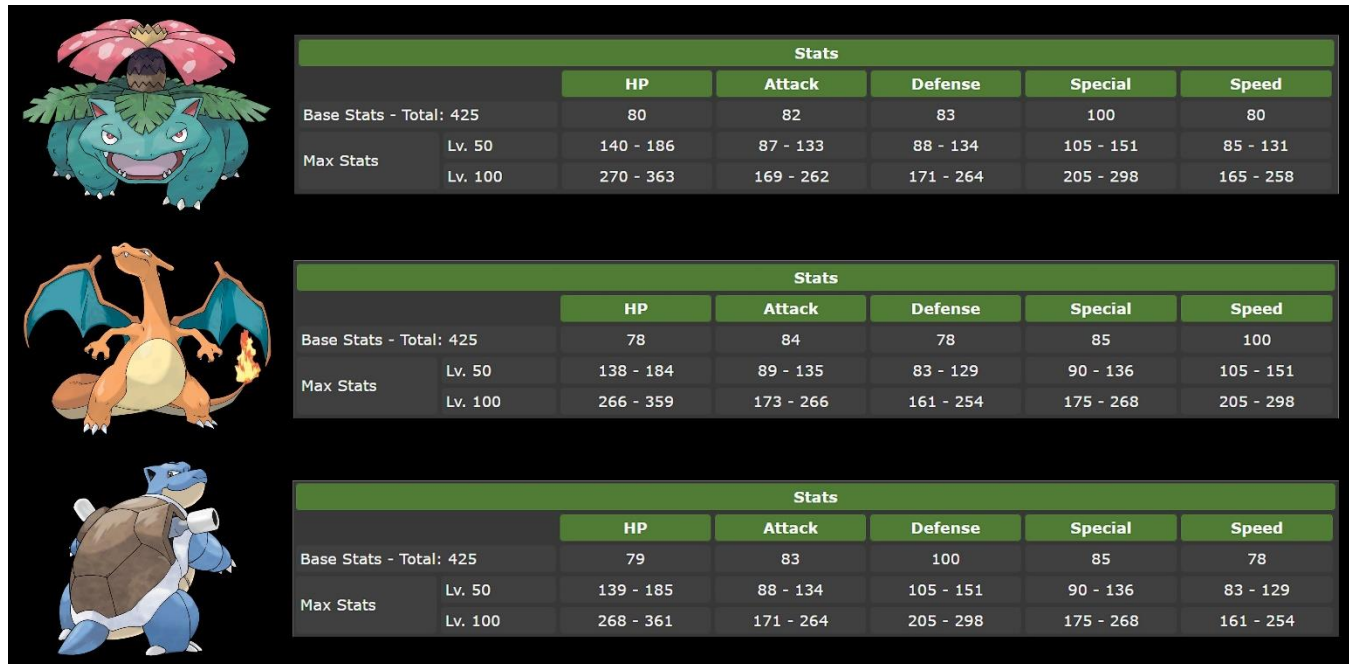


Figure 1. Base stats of (from top to bottom) Venusaur, Charizard and Blastoise in Gen I. Source of the tables: Serebii.net. Original artwork of the Pokémon by Ken Sugimori; available through Bulbapedia.

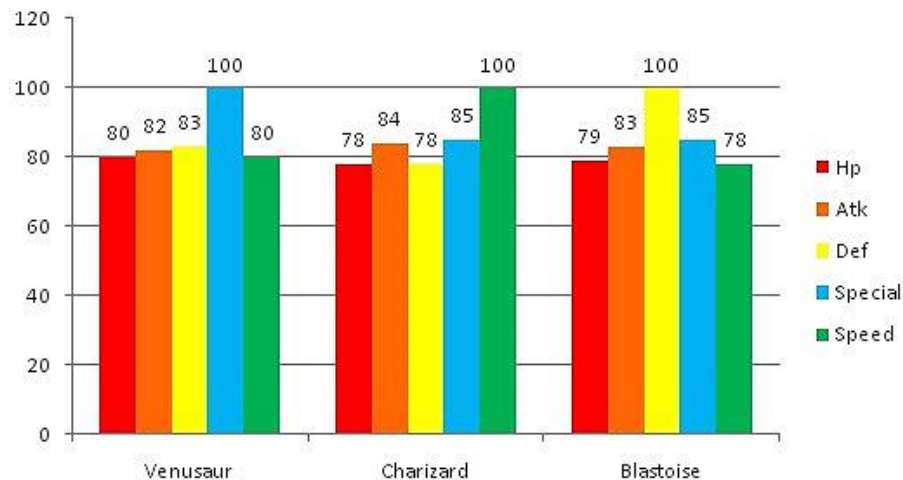


Figure 2. Chart comparing the Base Stats of the three starters in Gen I.

By comparing the so-called Base Stats of the three starting Pokémon (from Fig. 1), we get the chart shown in Figure 2. This gives us a broader view of the Stats distribution of each Pokémon, distinguishing their higher and lower attributes. If we add up all the Base Stats of each Pokémon, we obtain a grand total score of Stats points (Fig. 3). From Figure 3, it can be

seen that all three Pokémon sum up to the same value: 425 points. In the first versions of the games the Stats were kept in a balance during the development of these three Pokémon. Thus, the sum of Base Stats alone is not enough to show which starter is the strongest. There's more to consider.

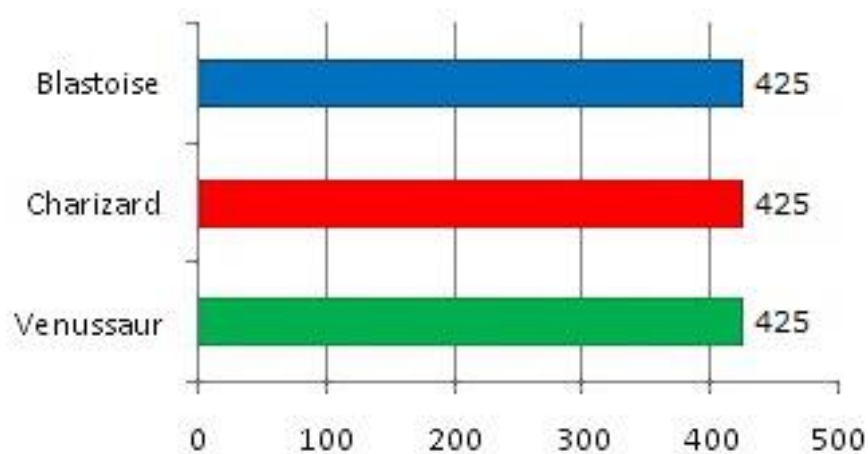


Figure 3. Sum of all Base Stats values of each starter Pokémon in its final form (Gen I).

Using the Base Stats, we can estimate the possible amount of damage (measured in hit points, or HP; Vianna Sym, 2015) that a Pokémon can cause with one of his moves. This is in fact based on a complex calculation

depending on several variables, such as the attacking Pokémon's level and offensive Stat and the opponent's defensive Stat, alongside some occasional bonuses. By default, the formula is expressed as (Vianna Sym, 2015):

$$Damage = \left[\left(\left(\frac{2}{5} \times Level \right) + 2 \right) \times \frac{AttackStat}{DefenseStat} \times \frac{AttackPower}{50} + 2 \right] \times STAB \times Weakness \times \frac{RandomNumber}{100}$$

where "Level" is the current character level of the attacking Pokémon, ranging between 1 and 100; "AttackStat" is the Base Attack Stat or Special Stat (depending on the kind of move, Physical or Special, used) of the attacking Pokémon; "DefenseStat" is the Base Defense


Stat or Special Stat (again, depending on the kind of move used) of the opponent; "AttackPower" is the power of the move used (this is pre-defined in the game and each move has its own power value), where a greater value represents a greater damage output; "STAB" is


an acronym for “Same-Type Attack Bonus”, which means that if the move used has the same type as that of the Pokémon using it, it increases in 50% (STAB = 1.5; otherwise, STAB = 1); “Weakness” is applied depending on whether the chosen move is super effective on the opponent (this variable can assume values of 0.25, 0.5, 1, 2 or 4, depending on the type of the move and of the defending Pokémon); “RandomNumber” is simply an integer assigned randomly by the game, ranging from 85 to 100.

Other in-game factors may cause changes in damage output, for example: weather effects (rain and sunshine), and the so-called “buffs” and “de-buffs”, which are respectively temporary increases and decreases in the

Pokémon’s Stats caused by moves such as *Agility*, *Dragon Dance*, *Swords Dance* etc. Weather effects were not yet present in the first versions of the game, so they will not be considered in this study. Moreover, to keep the analysis simple (not to say feasible), increases/decreases in Stats will also not be taken into account. The calculations here use only the Base Stats of the Pokémon in question and the set Power value of the moves. Weakness will also not be applied.

Codd (2016) considered the “signature moves” of the starting Pokémon as: Solar Beam for Venusaur (grass type), Flamethrower for Charizard (fire type), and Hydro Pump for Blastoise (water type).

Attack Name	Battle Type	Category
Solarbeam ソーラービーム	GRASS	
Power Points	Base Power	Accuracy
10	120	100

Attack Name	Battle Type	Category
Flamethrower かえんほうしゃ	FIRE	
Power Points	Base Power	Accuracy
15	95	100


Attack Name	Battle Type	Category
Hydro Pump ハイドロポンプ	WATER	
Power Points	Base Power	Accuracy
5	120	80

Figure 4. From top to bottom, the moves Solar Beam (formerly rendered as “Solarbeam” or “SolarBeam”), Flamethrower and Hydro Pump, showing their in-game Power values and type (in Gen I). The symbol in the “Category” entry means that the moves are all Special Attacks. Source: Serebii.net.

The Power of each of these moves can be seen in Figure 4, alongside other data: “Battle Type” is the type of the moves, which in this case are the same as the types of the starter

Pokémon (so STAB = 1.5); “Category” refers to whether the move is a Physical Attack or a Special Attack (all are Special and thus use the Base Special Stat); “Power Points” (PP)

represent the number of times that the move can be used; “Power Base” is the Power of the move (used in the equation above); “Accuracy” refers to the probability of success in hitting the opponent (in %).

CALCULATING THE DAMAGE

To calculate the damage dealt by each of the starter Pokémon with their signature moves, I used a virtual calculator available at

Smogon University, the “Pokémon Showdown”. (Smogon University is a community dedicated to the competitive world of Pokémon games, giving the players some useful tools.) The moves have the Power values shown in Figure 4 and the defending Pokémon will be a Chansey (see Fig. 5 for Base Stats), which is neutral (that means, neither weak nor strong) towards the starters and their signature moves. All Pokémon are considered to be Level 100.



Stats						
		HP	Attack	Defense	Special	Speed
Base Stats - Total: 415		250	5	5	105	50
Max Stats	Lv. 50	310 - 356	10 - 56	10 - 56	110 - 156	55 - 101
	Lv. 100	610 - 703	15 - 108	15 - 108	215 - 308	105 - 198

Figure 5. Base stats of Chansey in Gen I. Source of the table: Serebii.net. Original artwork of the Pokémon by Ken Sugimori; available through Bulbapedia.

By putting all the values in the Pokémon Showdown calculator, we have:

▪ **Venusaur (Solar Beam):** Note that the Gen I version of Solar Beam is not present in the Pokémon Showdown database, so I used the Gen II version instead (the Power is the same). The damage output falls in the interval 125 to 147 points, which represents 17 to 20% of Chansey’s total HP. Venusaur needs to land 5 blows to knock out its target.

▪ **Charizard (Flamethrower):** The damage output falls in the interval 90 to 106 points, which represents 12 to 15% of Chansey’s total HP. Charizard needs to land 7 blows to knock out its target.

▪ **Blastoise (Hydro Pump):** The damage output falls in the interval 113 to 133 points, which represents 16 to 18% of Chansey’s

total HP. Blastoise needs to land 6 blows to knock out its target.

Just in case, these numbers were checked on another calculator, built by myself (Pokémon Damage Calculator; Carli, 2016). An algorithm was developed based on the damage equation from above, translated in some programming languages (available at: <https://github.com/brunolcarli/pokeDamageCalculator>) and then translated into APK format so it can be installed on any mobile device running on Android (Fig. 6) or Windows operating systems. Feel free to download the app at: <https://build.phonegap.com/apps/1824036/install>. The results were very similar (Fig. 6): 127 to 144 points of damage for Venusaur’s Solar Beam; 84 to 98 points of damage for Charizard’s Flamethrower; and 106 to 122 points of damage for Blastoise’s Hydro Pump.

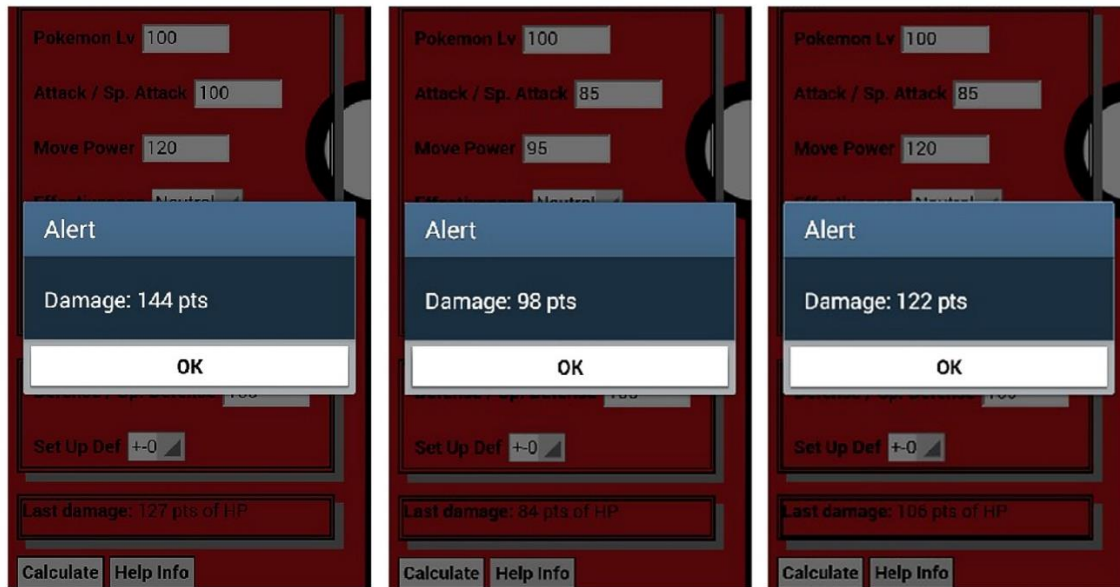


Figure 6. Screenshots of the Pokémon Damage Calculator app (Carli, 2016: v. 1.0.0, running on Android OS), showing the maximum damage output for Venusaur's Solar Beam (left), Charizard's Flamethrower (middle) and Blastoise's Hydro Pump (right).

Organizing all these numbers (from both the Pokémon Showdown and the Pokémon Damage Calculator) in a chart (Fig. 7), it is possible to clearly see the minimum and maximum damage each of the initial Pokémon can inflict, with their signature moves, against a neutral target. It can be seen that Charizard is actually the Pokémon that causes the least amount of damage, while Venusaur can deal the greatest amount of damage. Thus, Venusaur can be regarded as the “most potent” starter if we are referring to the sheer amount of damage caused.

CONCLUSION

The present study thus shows that Codd's (2016) analysis is not applicable to the game itself, since it is not based on the variables and values present in the game mechanics. Also, as shown above, Venusaur and not Charizard is

the “most potent” starter considering just the raw amount of damage it can cause. However, this is true only for a single attack in a single round of battle (which is important for the so-called “one-hit knockout”). Of course, as every player knows, one should not think that damage output alone makes a Pokémon more effective in battle. The game has much greater complexity and we would be reducing it to nothing if we just consider maximum damage. For instance, Solar Beam is a move that needs to spend 1 turn of the battle recharging, while both Flamethrower and Hydro Pump can be used every round. Furthermore, there are other factors, like Hydro Pump having an accuracy of 80% (meaning it misses one out of every five times) and Flamethrower being able to leave the defending Pokémon with the burn status condition. However, this is a matter for another day; for now, Charizard has lost its crown.

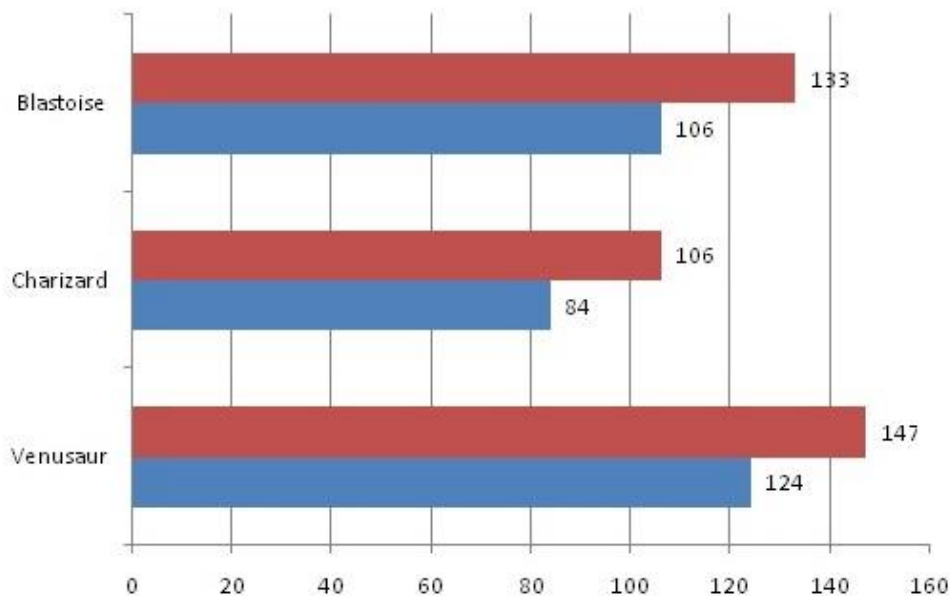


Figure 7. Simple chart showing the maximum (red) and minimum (blue) points of damage each of the starters can inflict with their signature moves (Solar Beam for Venusaur, Flamethrower for Charizard, and Hydro Pump for Blastoise). The chart takes into account the values obtained by both the Pokémon Showdown and the Pokémon Damage Calculator.

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Is the Great Attractor a Tengen Toppa Gurren Lagann?

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Space is a big place. Quite big, actually. Huge may be a more appropriate adjective. So huge that it received the title of “final frontier” by a famous television series, since you are not really supposed to traverse it. (The question remains, though: for it to be a frontier, isn’t it supposed to have something on both sides?) The vastness of space is both mysterious and fascinating. Man, in his ceaseless curiosity and desire for knowledge (and also the need to understand the universe around him to avoid the discomfort of death by starvation or cold), developed the science known today as Astronomy, as an attempt to unveil the mysteries of the universe. Since space is such a

humongous place, one can expect it is full of mysteries. Enters the Great Attractor.

THE GREAT ATTRACTOR

The Great Attractor is a gravitational anomaly, a massive (and controversial) one. It is indirectly “observable” by its effect on the motion of galaxies, and its presence, mass and position were estimated based on the peculiar velocity of the Local Group, the galaxy group that includes the Milky Way (Kocevski & Ebeling, 2006). A nice video explaining it was made by the SciShow Space (www.youtube.com/watch?v=N9qeOhJ9dbg). It is also a quite funny name with the potential for several jokes (Fig. 1 is not one of them, but it could be).

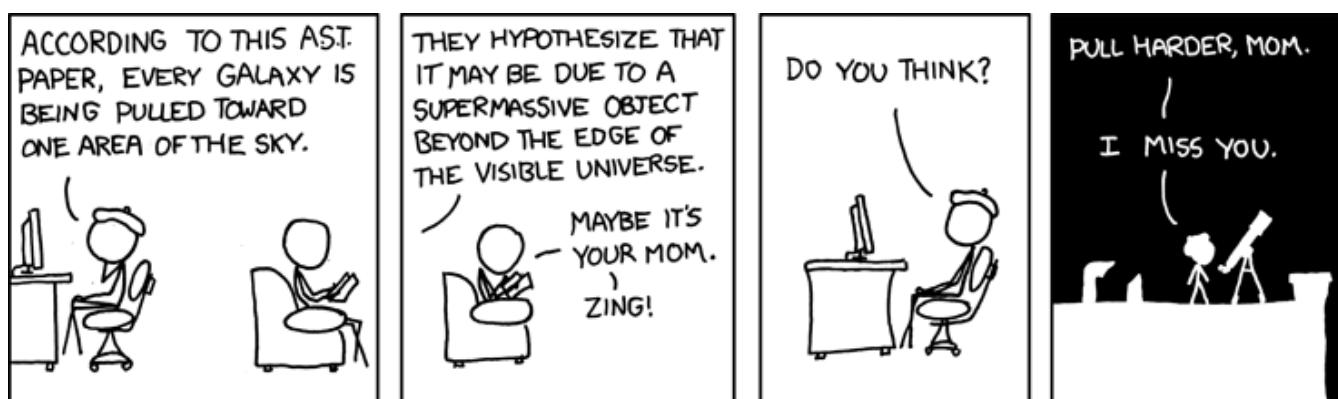


Figure 1. “Dark Flow” (XKCD, 2008; available from <https://xkcd.com/502/>). Note that the (rather controversial) Dark Flow phenomenon is not the same as the Great Attractor. I included this strip, though, because it is funny.

The observation of the Great Attractor is difficult when restricted to the length of optical waves, due to the presence of the Milky Way. The plane of the Milky Way outshines (due to its stars) and obscures (due to the dust) many of the objects behind it (NASA, 2013). This unobservable space is called the Zone of Avoidance (ZOA; a very neat name by the way), or “Zone of few Nebulae” as initially proposed by Proctor in 1878 (Kraan-Korteweg, 2000). Not to be confused with the Phantom Zone, the prison dimension to where the people of Krypton sent their prisoners.

The ZOA was “avoided” by astronomers because of the difficulties in analyzing the obscured galaxies known there (Kraan-Korteweg, 2000). Figure 2 shows a picture from the NASA/ESA Hubble Space Telescope taken in 2013 focusing on the Great Attractor. The region behind the center of the Milky Way, where the dust is thickest, is very difficult to observe at optical wavelengths.

In this study, I shall propose a slightly unusual hypothesis to what could be the Great Attractor. Could this gravity anomaly be an outcome of the presence of a very big robot?

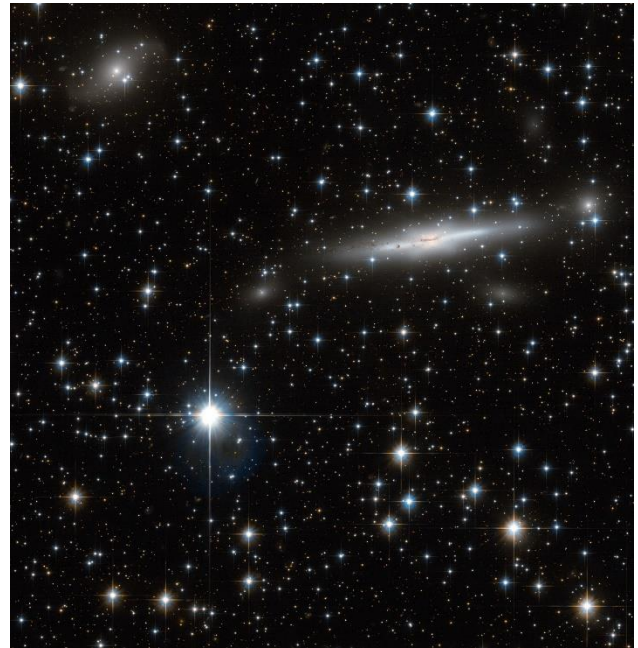


Figure 2. “Hubble Focuses on ‘the Great Attractor’”. This field covers part of the Norma Cluster as well as a dense area of the Milky Way. The Norma Cluster is the closest massive galaxy cluster to the Milky Way. The huge mass concentrated in this area and the consequent gravitational attraction makes this region of space known to the astronomers as the Great Attractor. Picture retrieved from http://www.nasa.gov/mission_pages/hubble/science/great-attractor.html (NASA, 2013).

Box 1. The Local Group, Clusters, Superclusters and other ginormous things

The Great Attractor’s location is estimated to be at a distance of somewhere between 150 and 250 million light-years from the Milky Way (something between 1.4×10^{24} and 2.4×10^{24} meters and quite far indeed). But both the Great Attractor and our own Milky Way belong to the same structure, known as the Laniakea Supercluster (“Laniakea” means “immense heaven” in Hawaiian). The Milky Way resides in the outskirts of this supercluster, whose diameter is 500 million light-years, while the Great Attractor resides closer to its center. A supercluster is a (very) large group of smaller galaxy clusters or galaxy groups (like our own Local Group) and is among the largest known structures of the cosmos. The Laniakea Supercluster was discovered in 2014, encompasses 100,000 galaxies, contains the mass of one hundred million billion Suns, and consists of four subparts, previously known as separate superclusters (The Daily Galaxy, 2015).

THE TENGEN TOPPA GURREN LAGANN

Japan has a peculiar relationship with robots, which have an important and established position in the country's pop culture. The word *mecha* (abbreviation of "mechanical") now refers to a whole genre of movies, manga, anime and live-action series (the *tokusatsu*) involving mechanical objects (vehicles, robots etc.), autonomous or manned, which quickly became popular in Japan and abroad.

While the first robot appearance in sci-fi culture is usually attributed to the tripods of H.G. Wells in 1897, the first appearance of a giant humanoid robot is attributed to Tetsujin 28-Go, a manga from 1956 by Mitsuteru Yokoyama. However, perhaps the greatest

symbol of the *mecha* genre, and Japanese culture in general, is from a 1952 manga by Osamu Tezuka: the boy-robot *Tetsuwan Atom* (Astro Boy in the West). This manga was released in post-war Japan, a moment of drastic changes in culture, industry and society, where science and technology promised economic growth and transformation of social structures (Hikawa, 2013). Astro Boy was adapted into anime in the 1960s and quickly made its way to the West. Other works of the *mecha* genre, particularly those with giant robots (e.g., Gundam, Mazinger Z, Macross, Neon Genesis Evangelion) influenced many western works like the *Transformers* cartoon, the *Power Rangers* TV series and the movie *Pacific Rim*.

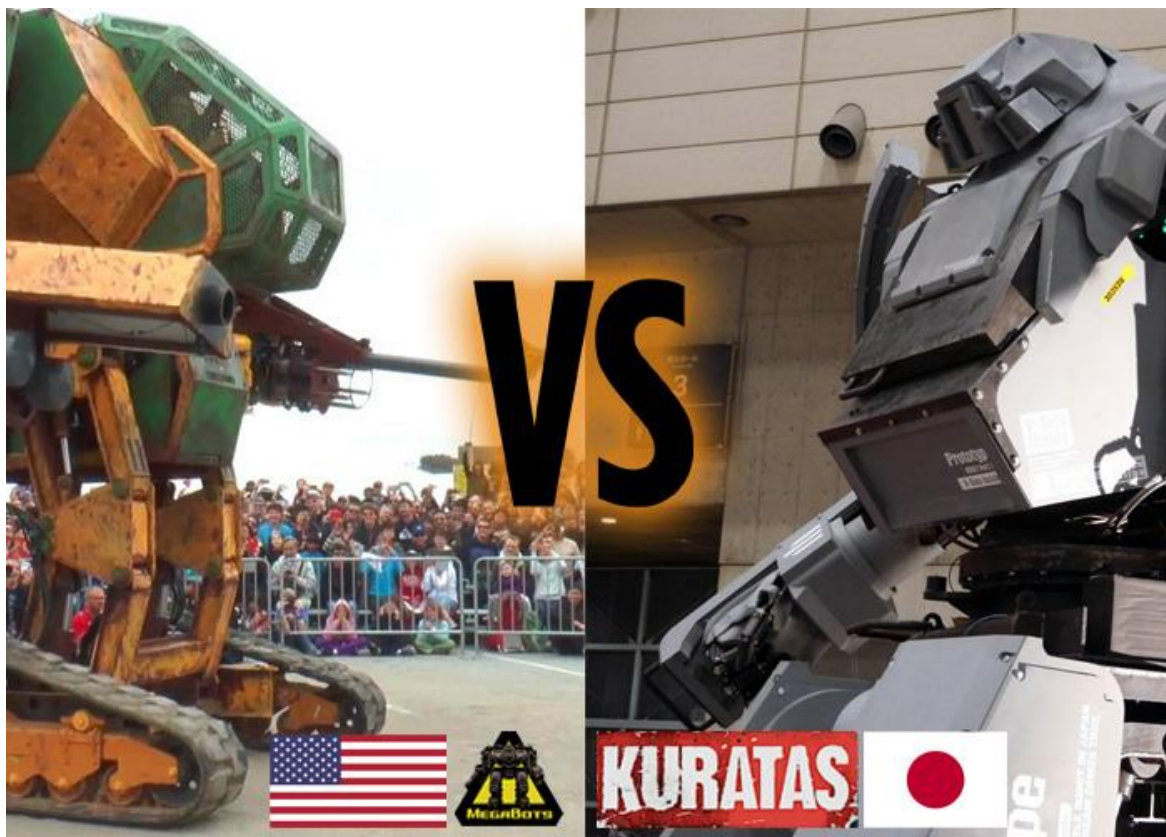


Figure 3. The American (Megabots Inc.) and Japanese, named Kurata, giant robots (Suidobashi Heavy Industries). Source: <http://www.popularairsoft.com/megabot-challenges-japanese-kuratas-giant-robot-duel>.

Giant fighting robots are already a reality, by the way. Groups of American and Japanese engineers, in their desire to hasten Judgment Day, built giant robots of a few tons, capable of firing missiles and engaging in heavy fighting (Fig. 3).

What does this entire story about Japanese robots have to do with the massive gravity anomaly from the introduction, you ask? Well, a 2007 Japanese animation called *Tengen Toppa Gurren Lagann* decided to explore how “giant” a giant robot could be.



Figure 4. The Tengen Toppa Gurren Lagann, a quite big *mecha*. Official artwork from the series, available from Gurren Lagann Wiki.

The Tengen Toppa Gurren Lagann (henceforth TTGL; Fig. 4) is the largest mecha shown in the anime. According to the official series guide, the TTGL is about 10 million light-years tall (Gurren Lagann Wiki, 2016). This is somewhere around 9.46×10^{22} meters, or about 100 times the diameter of the Milky Way. It is a fairly giant robot.

The existence of a robot 10 million light-years tall is very questionable for some practical reasons. The usefulness of a robot of this size is also doubtful. How could a robot of this size engage in combat (or do anything, actually)? Since nothing restricted by the physics of our universe can move faster than light, the act of throwing a single punch would take a few million years. It would take a few million years more for the pilot of this robot to find whether the punch hit the target or not. It would be a long fight. These practical questions will henceforth be disregarded here. The question posed is only one: could the Great Attractor be a consequence of the existence of the TTGL?

Box 2. The Super TTGL

In the follow-up movie, a version of the robot entitled Super Tengen Toppa Gurren Lagann was introduced because, why not? The Super TTGL is 52.8 billion light-years tall according to the official guide book, making it about 58% the size of the universe. We shall not consider this robot.

SO... IS IT POSSIBLE?

Well, not exactly.

The first thing I need to do is estimating what is the mass of a robot of this size. This is not that simple, since humanity has not yet

been able to build something so gargantuan. A rather crude way to do this is by applying the square-cube law (see Box 3) based on smaller robots with known mass. Since we have the

height and mass of the Kurata Japanese robot (4 meters, 4.5 tons; Wikipedia, 2016a), we can use it for our estimate.

Box 3. The square-cube law

The square-cube law was proposed by Galileo Galilei (1564–1642), who was apparently the first to notice that the volume of a particular object or being increased in cubic proportion to an increase in their linear dimensions, while the strength increases in square proportion (cross section of the muscles). A review of this concept was conducted by Froese (2006).

The square-cube law has a number of practical applications, including studies in Biology and civil engineering, besides being a very interesting concept to be assessed in pop culture. It is not uncommon that, for super heroes, strength and size are treated almost synonymously. Heroes and villains (*e.g.*, the Hulk, Giganta, and Apache Chief), grow in size constantly for fighting or performing feats of strength. In practice, achieving an absurd size is not practical, since the square-cube law suggests that the weight of the heroes grow much faster than their strength (that would mean they would be unable to even stand up). This law is unfortunately a significant impediment to building colossal robots.

Interestingly, the spell *enlarge person* from the tabletop RPG Dungeons & Dragons agrees with half of the law (Cook et al., 2003). To double in size, the target of the spell has its weight multiplied by eight, in accordance with the “cube law”. However, the target receives a fixed Strength modifier of +2, instead of having an increase proportional to his/her base Strength value, which would make more sense.

Applying the square-cube law to estimate the mass of the TTGL, we get the results shown on Table 1. In addition to the mass of the TTGL, I estimated the mass of other fictitious robots. This comparison was made to assess whether this estimate would be appropriate, given that several of these giant robots have established weights in official guides and other “literature”.

The robots chosen for comparison were: the *ATM-09-ST VOTOM* (Vertical One-man Tank for Offense and Maneuvers) from the anime *Armored Trooper Votoms* (1983); the *Gundam RX-78-2* from the anime *Mobile Suit Gundam* (1979); the *T800* from the movie *Terminator* (1984; the height was defined as that of the actor Arnold Schwarzenegger; the weight of a *T800* is unknown but it is thought to not exceed 1 ton, since the robot take actions such as riding a motorcycle); the *autobot Optimus*

Prime from the movie *Transformers* (2007); the *jaeger Gipsy Danger* from the movie *Pacific Rim* (2013); and the real robot from Megabots Inc. mentioned above (the weight of the Megabot is known; the estimate is only for comparison purposes). Moreover, Table 1 has also the Sun and the Milky Way for comparison. We can see that, for larger robots (Optimus Prime and bigger), the estimated weight by the square-cube law becomes much greater than that given by the official guides. This lighter weights can be partially “explained” for some robots by using unknown material: Optimus Prime is made of Cybertron materials and Gundams from *Luna Titanium* or *Gundarium*. In the case of a Jaeger, I can only assume that the futuristic technology of Pacific Rim was able to develop lightweight robots to that extent (or that the movie producers just did not care).

Table 1. Height and weight of giant robots and other things. The “Estimate” column is the weight estimated using the square-cube law (having Kurata’s weight and height as basis). The “Official” column is the official (or actual) weight.

Robot	Height (m)	Weight (ton)		Source
		Estimate	Official	
T800 (Terminator)	1.88	0.5	—	Wikipedia (2016b)
Kurata (real)	4.00	4.5	4.5	Wikipedia (2016a)
Megabot (real)	4.57	6.7	5.4	Blain (2015)
ATM-09-ST (Scopelog) VOTOM	3.80	3.9	6.4	MAHQ (2016)
Optimus Prime (movies)	9.75	65.2	4.3	Transformers Wiki (2016)
RX-78-2 Gundam	18.50	445.2	60.0	Gundam Wiki (2016)
Gipsy Danger (Jaeger)	79.00	34,666.8	1,980.0	Pacific Rim Wiki (2016)
Tengen Toppa Gurren Lagann	9.5E+22	6.0E+67	—	Gurren Lagann Wiki (2016)
Sun	1.4E+09	1.9E+26	2.0E+27	Wikipedia (2016c)
Milky Way	3.0E+08	1.9E+24	1.7E+39	Wikipedia (2016d)

The mass of the Great Attractor is estimated to be about 1.000 trillion times the mass of the Sun (Koberlein, 2014). This is equivalent to circa 2×10^{42} tons, well below the estimated mass of a TTGL of 6×10^{67} tons. Just from this difference, it appears that the Great Attractor could not be a TTGL, or the gravitational attraction would be many times stronger than the one perceived (even considering that the estimated weight is wrong by a few orders of magnitude). Moreover, this is not the only problem. Such a monstrous mass distributed in such a small space would probably collapse and become a black hole.

The Schwarzschild radius (or gravitational radius) is a concept that expresses what should be the radius of a sphere such that, if the mass of the entire object was within this sphere, the escape velocity of the surface of this sphere would be equal to the speed of light (*i.e.*, you would not be able to escape its gravitational field). When the remains of a star, for example, collapse so that its size is below this radius, the

light cannot escape its gravitational field and the object is no longer visible, becoming a black hole (Beiser, 2003). The Schwarzschild radius can be calculated by:

$$r_s = \frac{2MG}{c^2}$$

where: **rs** is the Schwarzschild radius; **G** is the gravitational constant; **M** is the mass of the object; and **c** is the speed of light in vacuum.

An object whose real radius is smaller than its Schwarzschild radius is called a black hole. Calculating the Schwarzschild radius for the Milky Way, the Sun, and the TTGL gives us Table 2.

Table 2. Comparison of the Schwarzschild radii of Sun, Milky Way and TTGL, with their real radii. The real radius of the TTGL is considered half its height.

	Schwartzschild Radius	Real Radius	Schwartzschild / Real
Sun	3.0E+03	7.0E+08	4.2E-06
Milky Way	2.5E+15	4.7E+20	5.3E-06
TTGL	8.8E+43	4.7E+22	1.9E+21

From Table 2, we can see that in the case of the TTGL, the Schwarzschild radius is many times larger than its actual size (even considering that the square-cube law has overestimated the mass of the robot by some orders of magnitude). This means that the robot, if existed, would become a giant supermassive black hole.

Incidentally, the estimated mass of the TTGL is also several times greater than the estimated mass of the observable universe (considering only ordinary matter), that is 10^{50} tons. Thus, it is unlikely that a robot this big exists.

SO... IS IT IMPOSSIBLE?

Well, not necessarily.

As shown by Table 1, many other robots in fiction do not follow the square-cube law to the letter. Some reasons may be proposed: they are made of fictional materials (supposedly not yet discovered by man), such as Gundarium or some Cybertron material; they were built by advanced and/or alien technology; or for any magical/supernatural reasons.

The same can be valid for the TTGL, in a way. The robot is made of “a mass of continuously materialized Spiral Power”, according to the anime lore (Gurren Lagann Wiki, 2016). This Spiral Power (Fig. 5) is presented in the anime as a physical model, the connection between living beings and the universe (besides being a religion of sorts). Such definition could make us treat the structure of the TTGL as strictly “magical”, discarding any physical interpretation of its existence. Nevertheless, the robot is composed of “mass”, so it has a gravitational field.



Figure 5. The protagonist of the Tengen Toppa Gurren Lagann anime overflowing with Spiral Power. Screenshot from the anime; image taken from Gurren Lagann Wiki.

As such, I propose a second analysis for the TTGL. Knowing the estimated mass of the Great Attractor as 2×10^{42} tons, I assume that to be the mass of the TTGL. Calculating the Schwarzschild radius for that mass, we have Table 3.

Table 3. Comparison of the Schwarzschild radius of the TTGL with its real radius, considering that the TTGL has the same mass as the Great Attractor.

	Schwartzschild Radius	Real Radius	Schwartzschild / Real
Sun	3.0E+03	7.0E+08	4.2E-06
Milky Way	2.5E+15	4.7E+20	5.3E-06
TTGL (estimated mass)	8.8E+43	4.7E+22	1.9E+21
TTGL (Great Attractor mass)	3.0E+18	4.7E+22	6.2E-05

Thus, a *mecha* of this size and weight might not collapse into a black hole, also having a “Schwartzschild radius / real radius” ratio not so different from those of the Sun and Milky Way.

SO... IT IS POSSIBLE!

Well, not really.

You see, early this year, scientists managed to identify a whole bunch of galaxies hidden in

the Zone of Avoidance (Staveley-Smith et al., 2016). These researchers used a multibeam receiver on a 64-m Parkes radio telescope and uncovered 883 galaxies, many of which were never seen before.

Therefore, it is more likely that the gravity anomaly detected is because of this concentration of galaxies rather than due to the existence of a giant robot 10 million light-years tall. But you never know...

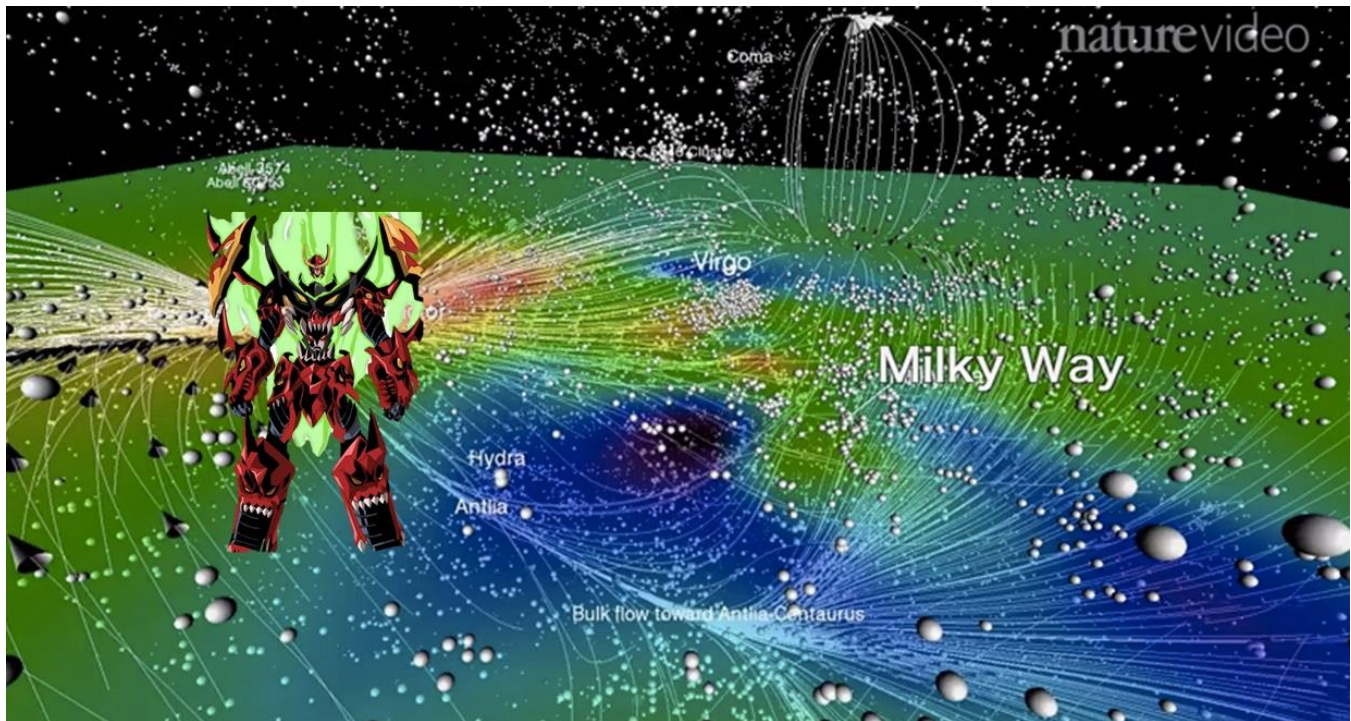


Figure 6. You never know... Image adapted from the video “Laniakea: our home supercluster”, by Nature Video; available from: <https://www.youtube.com/watch?v=rENyyRwxpHo>.

Box 4. The Ring (1994)

In his 1994 novel “The Ring”, fourth book of the “Xeelee Sequence”, British hard science fiction writer Stephen Baxter proposed yet another interesting hypothesis for the origin of the Great Attractor. In his novel, the alien race Xeelee was losing a war against beings of dark matter, and retreated through an escape hatch. This escape hatch (the Ring from the title) was made of something too small to be seen by the naked eye, a cosmic string, a flaw in space time. A single inch of this “material” would weight ten million billion tons on the surface of the Earth. The ring had a mass of several galactic clusters and measured 300 light-years across, 10 million light-years in diameter. In Baxter’s book, it is discovered that this immense construction is the reason behind the Great Attractor (Orbital Vector, 2007).

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