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The Mathematics of Lego

By Samuel Arbesman ✉ January 6, 2012 | 6:35 am | Categories: Science Blogs, Social Dimension

The world of toys and games is not immune to mathematics. From the Rubik's Cube to Monopoly, fun pastimes can be quantified. And the same is true of Legos. Lego blocks, the building toys that are truly amazing and that I have never quite grown out of, are amenable to math.

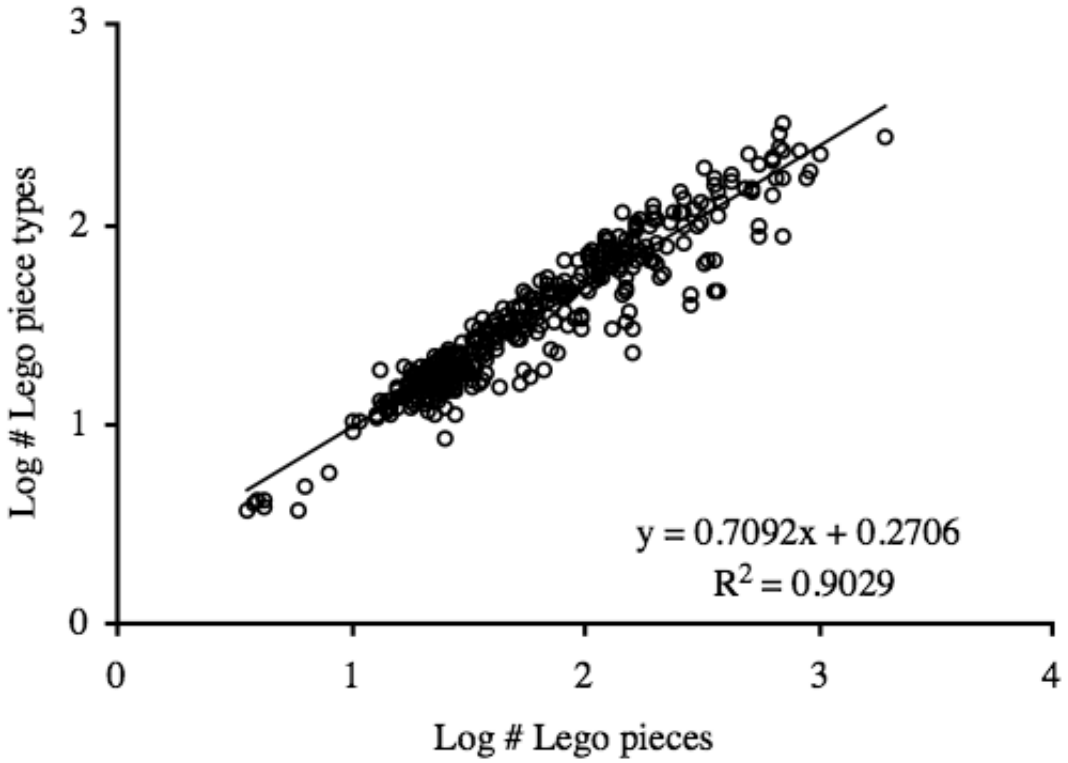
To see that, we have to begin thinking about how we combine things together. Most objects are made up of smaller parts, combined in complicated and diverse ways. Whether it's a circuit that is made up of components such as resistors and capacitors, or a living thing that has different types of cells—muscle cells, neurons, and more—there is a certain diversity to the number of types of components that go into building a system. But how does the variety of pieces grow with the size of the system? Do larger circuits have more types of pieces? Or do they always use the same handful of parts—nothing more than resistors and capacitors—to make larger and more complex systems?

In the wonderfully titled paper Scaling of Differentiation in Networks: Nervous Systems, Organisms, Ant Colonies, Ecosystems, Businesses, Universities, Cities, Electronic Circuits, and Legos, Mark Changizi and his colleagues set

out to understand this concept. They found that in every single one of the systems in the wildly interdisciplinary list of the subtitle there was an increase in the number of types of components as the total number of pieces grew. The larger something is, the more types of building blocks it uses.

And this includes, of course, Lego bricks. Using a dataset of 389 Lego sets (this was done back in 2002, so if anyone can download the data easily, I would love to see if the results hold up with a richer dataset), they examined the number of distinct types of pieces in a set versus the total number of pieces in that set (examples of sets include "Air Patrol", "Spy Boat", and "Cargo Crane", and a master list of Lego piece types is here).

They found that the number of piece types to total number of pieces could be fit nicely to a power law. Here it is on a log-log scale:



This curve demonstrates that as the number of pieces in a set grows, so do the number of piece types. However, the number of piece types grows *sublinearly*: while a larger set uses more piece types, as sets becomes larger, they use progressively fewer additional piece types (so larger sets actually use fewer types per piece). This is similar to other sublinear curves, where larger animals use less energy per cell for metabolism or larger cities actually need fewer gas stations per capita. Essentially, larger sets become more efficient, using the same pieces that smaller sets do, but in a more complex and diverse way.

While the authors use a rather complicated optimization argument, this can be seen somewhat more intuitively: when a system is under some form of selection (and in the case of Lego, they argue for some form of economic selection), it becomes more costly to grow the system and create new types of pieces. Therefore, it makes sense to use the same types of pieces more efficiently. Intriguingly, the authors also find that there are fewer types of components in natural systems than in human-created systems (for a given size), which makes sense, as evolution takes more time to invent a new part than a designer and a factory do to create a new customized Lego piece.

I have seen other research that uses Lego pieces as building blocks, but this is the first study I have come across that actually examines pre-existing Lego sets as systems themselves. Now I just want to see a paper that compares the different Lego systems and can prove to me the superiority of Lego City and Technic over Harry Potter or Pharoah's Quest.

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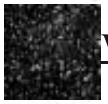
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