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Created by: François Xavier Vives
English script French version
A world in folds
The Origami Code

COMMENTAIRE: INTRO

01:00:08
In Japan, a country steeped in tradition, generations of children learn the art of folding things into nice little objects, starting with the most simple of forms, a square sheet of paper!

01:00:23
The most well-known folded paper today is without doubt, the crane. Not only has this elegant Japanese paper crane become the symbol of the art of paper-folding known as “origami”, it is even considered a symbol of Japan itself. In Japanese, “Ori” means “fold” and “Kami” means “paper”…

01:00:41
Over time, the practice of folding paper has been elevated to a form of art, driven by the spectacular inventiveness of its great masters.

01:00:49
Over the last few decades, this small world of origami has been making waves like never before to the point that it is now taking on a whole new scientific dimension! No field of research has been spared by the fascination for this ancestral art of paper-folding. A cross between art and geometry, origami is slowly permeating every area of our lives.

01:01:11
And by exploring the various systems of folds around us, researchers are discovering that nature itself is the grand master of origami!

01:01:20
Understanding these mechanisms may even lead to more than mere technological progress but to a new concept of organising forms in nature; a new vision of a world unveiled through origami… the revelation of a world in folds perhaps?

TC: 01:01:36

Titre: A world in folds - the Origami Code

Erik and Martin Demaine IN

01:01:56
Martin Demaine
Do you want to look at the curved folding?

01:01:59
Erik Demaine
Wow... Is this a new brand gen octopus ? The details on the suckers, on the tentacules. It's very lifelike.

01:02:11
Commentaire
Erik and Martin Demaine admire the beautiful origamis on display at the international Tanteidan convention in Tokyo.

01:02:26
Erik Demaine
Cool... this is the work of Barry Hayes !

01:02:31
Commentaire
Always the same starting point; a single sheet of paper; a myriad of folds and then… an infinite variety of creations!

Erik and Martin Demaine IN

01:02:42
Erik Demaine
It's just like that...

Martin Demaine
Oh it's really well done!

01:02:44
Erik Demaine
You know humans started with their back's arched and now they resumed their arched backs.

01:02:50
Martin Demaine

Haha

01:02:52
Erik Demaine
It's crazy!

Commentaire

01:02:54
But Erik and Martin Demaine are not just any origamists from the US; Martin, the father, teaches art at MIT in Boston, whilst Erik is a researcher in mathematics and applied informatics at the same famous institute. They are both well-known authorities in the origami world, renowned for their artistic and scientific contribution.

01:03:15
Erik Demaine IN in class
My father and my explorations into combining art and science through origami...

01:03:23
Erik Demaine
For me origami offered a very interesting geometrical challenge. The idea that you have one sheet of material, all you can do is fold it, no cutting, mathematically. You can't stretch the material and it's not allowed to intersect itself. Those seem like very simple rules and yet I was looking at the art that was possible with origami and it seemed very powerful.

Commentaire

01:03:51
Erik and Martin take advantage of the convention to meet the legendary Tomoko Fuse, venerated in the art of origami as a national treasure of Japan… Erik is moved; he discovered origami through Tomoko's work. No sooner had they met than they were already reminiscing on past projects; artist meets scientist in mutual admiration. This is the image of the new era being unveiled in the world of origami.

Exchange between Tomoko Fuse and Erik Demaine IN

01:04:16
Martin Demaine

And soon... we will work together...

01:04:20
Erik Demaine
Make something!

01:04:21
Tomoko Fuse
Yeah make something... something new.

01:04:24
Martin Demaine
Something new yeah!

Commentaire

01:04:42
At her traditional house perched on a mountain in the Nagano prefecture, Tomoko Fuse reflects, folds and invents new kinds of origami.

01:04:55
She is quietly adding her modern touch to the art of paper-folding.

01:05:04
In recent years, science has been paying closer attention to her work.

01:05:11
Just like Erik Demaine, many scientists have been captivated by the geometric enigma of the art of paper-folding.

01:05:22
Paper models such as the ones Tomoko creates are as puzzling to mathematicians as they are inspiring, when you are trying to design lightweight, transformable, modular structures made in one piece…

01:05:38
A few folds to a sheet and up springs an amazing structure!

Commentaire

01:05:52
In the north of Japan, the University of Hokkaido gradually disappears under ice and snow. This is where the young and talented engineer, Kaori Kuribayashi, carries out her research into new medical instruments.

01:06:07
It is from a creation by Tomoko Fuse that Kaori got the idea that origami could probably improve the design of “stents”, a key tool in the treatment of cardiovascular diseases. The small mesh tubes are placed in arteries to help restore them to their normal size.

01:06:25
What are the limits of classic stents? They are made from several materials including metal and have to be inserted very carefully. Kaori’s stent could simplify all that…

01:06:37
Kaori Kuribayashi
I was looking for a particular pattern which can change a diameter. So you can see this, when you fold in this, the diameter really is small, but when we expand the diameter, making it quite large, that’s what I really wanted to find out.
We can put it inside our body like that using a catheter and then once they reach in a certain position like then, we can open it up like this.

Commentaire

01:07:10
The “origami” stent would be a single unit made of a material that expanded with body temperature. Once in position, the stent would deploy without the need for any external manipulation.

01:07:21
Kaori Kuribayashi
So we need to have this pattern - particulary - that kind of origami pattern to producing a new type of stent graft.

A pattern called a pineapple pattern or sea cucumber pattern. It’s one sheet of paper for all these patterns.

Commentaire

01:07:43
So maybe a small sheet of the appropriate material, folded in the right way could save lives…

01:07:50
It all relies on what origamists call “crease patterns”, i.e., the pattern drawn on the initial sheet showing you how to fold the paper and in what order. By following the crease pattern step by step, a flat sheet of paper is transformed into a volume; from 2D into 3D. That could lead to an infinite possibilities of patterns, limited only by one’s imagination. A feat of human creation!

01:08:17
But is this solely the fruit of human endeavours?

Commentaire

01:08:23
The architect and designer, Biruta Kresling, approaches this from an amazing angle…

01:08:29
Although preparing for the demonstration takes a few minutes, Biruta says she can create very complex origami in less than one … second!

Indeed, she calls it “instant” origami!

01:08:44
Biruta Kriesling
Mit den Papierkegeln, die wir gestaucht haben, haben wir wieder eine Instant-Origami-Figur geschaffen, eine spontane Faltstruktur die ganz ohne Einwirkung einer wissenden Hand, entsteht automatisch, spontan, in einer Sekunde

We have pressed the paper cones to create a model of instant origami; a folded structure that is created automatically – no intervention whatsoever, just spontaneously and within one second.

Dieser Papierkegel wurde zu einer logarithmischen Spirale, was typisch ist für jedes Wachstum in der Natur, was in Form von Rohren oder von Kegeln wächst (wie zum Beispiel)

This crumpled paper cone follows a logarithmic spiral that is typical in nature during the growth phase of things that grow into a conical shape, such as pine codes.

Commentaire

01:09:24
Biruta Kresling tells us that this experience reveals that the natural organisation of matter appears to be based on folding. And this isn’t just an isolated coincidence; Biruta has encountered many instances of “instant origami” with different crease patterns.

01:09:42
Regardless of whether it is complex geometry or a simple pattern, nature practices origami!

01:09:51
Vincent Floederer

Just look at how diverse the natural vegetation that holds the slopes in place there is. It is inspiring. You can see simple patterns of grass structured around a single fold. You could call that parallel creasing because it is made up entirely of parallel lines. It's a bit early yet but you can see already the folds. You can see how it's all being formed.

Commentaire

01:10:31
Vincent Floderer has been observing nature and exploring the frontiers of origami from his studio on the slopes of a valley in Corrèze for over two decades. He has also discovered an amazing way to fold paper – by simply crumpling it! Of course, this implies bending the rules of traditional origami a bit.

01:10:53
Vincent Floederer
Origami means folded paper. And that is exactly what I do, even though I am just crumpling it up; it is in effect one folding with a lot of creases. Crumpling paper can involve hundreds, thousands and even millions of creases in some cases. So, when is a folding not a folding? It could be 100, 200, 1000, 2000 creases. Where does it end? What's certain is that they are all folds.

Commentaire

01:11:20
Vincent's crumpled paper with thousands of creases shows that there is some link between folding and nature. Of course, a mushroom or pine cone is slightly more intricate than folded paper and nature doesn't fold things like Vincent does but there is a striking resemblance in the shapes and textures …

01:11:43
Vincent Floederer
I have an example in my hand. It's not bad. Although it is no more than a series of rectangles, it does also look strikingly like a pine cone. It even makes a similar sound. When I unfold the shape, I get a series of rectangles. It's no more than a geometric construction that automatically assembles itself like that. That's what crumpling is all about. Now, doesn't this look like a sponge? It's made of modular, elastic shapes. To me it is series of… it is a hexagon paving. This makes you think of the phenomenon of convergence that you can find in 2 completely different environments. For example, you can find similar shapes in the sea and in a forest. Some corals are very similar to lichens or certain mushrooms. They have identical structures. Although they are made of different materials, you could say they share similar architectures. Indeed, it is also a question of architecture.

Commentaire

01:13:02
Therefore, it looks like natural architecture relies to some extent on crease patterns. But if so, why does nature practice origami? Where would lie the benefit? And how does nature create such complex crease patterns?

01:13:18
Just like northern Japan, Boston is also under several metres of snow when we meet Professor Mahadevan. He leads us to the heart of the Harvard arboretum, where he hopes to show us how the leaves of some trees fold during growth… A mathematician by training, he is a fervent admirer of nature's inventions. However, it's a harsh winter this year and the buds refuse to open up…

01:13:44
Mahadevan
Origami as an art form has existed for a relatively short time, but nature has essentially coopted origami in many different systems. And one of those systems turns out to be leaves. And in particular if you look at horn beam or beech leaves, you find that those leaves are essentially closed in their bud in a way which is very reminiscient of origami.
In fact, if you essentially look at a horn beam or a beech leaves in its bud you will find that the fold patterns have a structure rather similar to this.

The ideal situation in fact you would have seen a horn beam or beeches leaf inside its bud in a form similar to what I'm showing you here by holding it in my hand. If I had opened the bud I would have expected to see a small version of this.

Commentaire

01:14:49
It's an early spring in Paris, however, and this allows Biruta Kresling to admire the leaves of hornbeams and many other species that Mahadevan hoped to see in the cold in Boston. Indeed, researchers' assumptions about nature's crease patterns in such cases are confirmed. One type of pattern in particular is everywhere; the *Miura Ori*, named after Biruta's Japanese teacher, Professor Koryo Miura, who was the first to unveil it. Miura Ori seems to be a hit in nature!

01:15:25
Biruta Kriesling
Ich habe entdeckt, dass die Miura-Faltung, die eine sehr regelmäßige Aderung haben und Fältelungen haben und wenn man nun das Prinzip vergleicht, sieht man, dass ein Blatt eigentlich nur ein Detail von einer Miura-Faltung ist mit einer zentralen Ader hier und einer Fältelung, die seitlich abzweigt.

I discovered what Miura Ori is, with its very regular veining and pleats. When you compare the principle, you realise that a leaf is in effect only a detail of Miura-Ori, with its central vein here and a pleat branching off laterally.

Commentaire

01:15:50
Mahadevan rushes to the blackboard to illustrate how nature creates a Miura ori pattern…

01:15:57
Mahadevan
Think about the leaf as a relatively thin surface. And now it's growing. So it’s growing and it's growing, potentially in both directions. If it's growing potentially in both directions, so the thin sheet is growing faster than the bulk. And if it’s growing faster than the bulk as I’ve shown you in these pink arrows, the bulk compresses the thin sheet. So there are two extreme possibilities. One possibility to the thin sheet to just bend in the two directions so to form something which looks like the surface of a balloon for example relatively small. But if you do that or if the sheet does that then it will have to pull under the substrate because that’s the come out. And so that is energetically very expensive.
And there is another potential solution and the other potential solution is to have a much larger number of small bends and of course because it’s been compressed in both different directions to grow up I must also have it in the opposite direction. So we can see now that I will have bends in one direction, I’ll have bends in the other direction. Sharp bends and in between the sharp bends the sheet remains flat and the consequence is this structure.

So this tells you that the origami pattern is a consequence of growth associated with a growth stress because all patterns are not growing simultaneously and then a small thickness.

Commentaire

01:17:40
So, these complex geometrical patterns that look as if they were created by man are actually a result of physical constraints. One main constraint that origami patterns can resolve is the issue of the amount of space required to develop or contain a living structure. Origami can start off small and flat and then unfold into something 4 and a half times its initial size, in the case of a Miura Ori leaf.

01:18:08
Nature creates Miura Ori patterns and dozens of others that researchers are unveiling everyday: the “pineapple pattern” observed with Kaori, the “pine cone pattern” and even the “twist buckling” pattern.

Nature’s compulsion to fold is evident, and not only in plants!

Origami patterns are a great way to demonstrate how a wing quickly deploys for flight or retracts when at rest…

01:18:34
Mahadevan
I unfold it. Voilà. So there is this rather large and very beautiful wing and I just show you the reverse. The same thing when I fold it, it packs away and then it's packed. And let's do the same thing on the other side and just to show you an example of how this was. So this is the way the wing was folded and then it opens up, something like that...

This is my open wing... and this is my packed wing... Really beautiful... horn beetle from Thailand.

So evolution might have stambled into folding patterns repeteadly because those allow you to have larger surfaces in a constraint geometry, in a constraint volume. And so it's not therefore perhaps a surprise that you'll see origami like folding patterns in wings, insect wings, leaves, you'll see it in the gut and if I'm allowed a small generalization you see similar kinds of folding patterns even in cortex.

Commentaire

01:20:08
Mahadevan and his team are trying out some experiments to study pattern formation in organs … (including in the brain). They are trying to show that it is that same growth principle observed in leaves that is at work. Here, the model is made using two superimposed layers of gel. When dipped into a solvent, the top layer expands more than the lower layer. However, because it is held back by the lower layer, the top layer wrinkles and soon starts to resemble our grey matter …

01:20:48
Confronted with such a recurrence of patterns, it is difficult not to believe that there must be a universal natural architecture

01:20:57
But if it is, indeed, so universal, why are we only discovering it now?

01:21:03
In Weimar, a hub of German culture, the Catalan iconoclast historian, Joan Sallas, has been meticulously looking into the history of the art of folding…

01:21:18
Joan Sallas
Wenn man diese Bibliothek, diese Sammlung von Belegen, bibliographisch und dokumentarisch betrachtet, merkt man, dass in ganz unterschiedlichen Sprachen - mehr als 30 - dann sieht man, dass die Faltkunst ganz unterschiedliche

Entwicklungen gehabt hat - in Materialien, in Faltsequenzen, in Grundformen, in Modellen, in ästhetischen Objekten, Erkenntnissen. ...Und es gibt keinen Erfinder von der Falt-Kunst es ist einfach die Natur. Und die Menschen haben einfach versucht, dieses Falten in der Natur zu entdecken. Und dann haben sie auch die Falt-Techniken entwickelt und haben die Falt-Kunst gestaltet. Dieser Prozess der Entdeckung in allen Völkern, in allen Ländern, in allen Kulturen produziert, nicht nur in einer. Genauso wie das Papier dann auch nicht nur aus China kommt. Das Falten kommt auch nicht aus Japan.

When you look at this library and collection of documents closely – it's in over 30 languages – you will see that the art of folding has developed very differently in terms of materials used, patterns, folds, shapes, models and aesthetics… no one person can claim to have invented the folding technique. Indeed, it exists in nature and in our quest to emulate nature we have used, developed and personalised our techniques of folding.

This process happened in every country, culture. It is not limited to any one. Just as paper wasn't only invented in China, the art of folding is not unique to Japan.

Commentaire

01:22:24
Joan Sallas just has to consult any book from his collection to debunk conventional wisdom: like thinking that this art is inseparable from Asia, whereas he knows that it was also highly developed in Central Europe from the Renaissance and even earlier.

Or thinking that the art of folding didn't exist before paper was invented…

01:22:44
Joan Sallas
Bevor das Papier nach Europa kam, hat man ganz viel ohne Papier gefaltet. Man hat andere Materialien benutzt, zum Beispiel Leder, zum Beispiel Leinen, Stoffe aller Art und Weise, Naturmaterialien. Und das hat sich im Rahmen eines kulturellen Austauschs zwischen den verschiedenen Ländern, die seit der Antike in Europa waren, produziert. Und auch die Ägypter, Griechen, Römer haben das ausgetauscht und verbessert und nicht nur die Materialien, sondern auch die Falt-Techniken verbessert und auch konzeptuelle, symbolische Sachen, womit alle Projekte geprägt waren, die sie gefaltet haben. Und diese sind auch von einem zum anderen Land übertragen worden durch die Jahrhunderte.

Before paper came to Europe, folding was already widespread. People used other materials, such as leather, wool, all sorts of fabric, as a form of cultural exchange between European countries right for antiquity. The Egyptians, Greeks, Romans… they were all involved in this cultural exchange and improved not only materials but also their folding techniques, symbols and concepts. This knowledge was passed on from one country to another over the centuries.

Commentaire

01:23:29
Man has never stopped exploring the geometry of folds. In every human community, the aesthetics and complexity of origami require a high level of knowledge. Acquiring such knowledge confers authority and power because mastering the complexity of folds means seeking to equal nature and master its fundamental laws.

01:23:56
Are contemporary masters of origami not also subconsciously seeking to equal nature's mastery of folds?

01:24:07
How are they going about that challenge today?

01:24:11
Let us ask a pioneer of the scientific origami revolution, the mathematician and relentless folder, Robert Lang. He maintains his link with nature by walking in the oak forests of California.

01:24:33
Once back in his studio, Robert starts working on a new fold. Today he is creating a spider; a black widow. His works have revolutionised and radically modernised the art of paper-folding. The initial stage of his work remains traditional; he analyses and measures the model and then transforms it into a simple skeleton so that it can be transposed into a crease pattern. What Robert has completely changed is that he has created a software called "Tree-maker" for generating crease patterns.

01:25:08
Robert Lang

So that's now a crease pattern for the spider. It's got all the parts. You can see roughly the allocation by the shapes that each of these hexagons are still outlining the legs. So there's a leg, front leg, middle leg, middle leg, back leg, back leg, middle leg, middle leg, front leg. This will be the body in the middle.

Commentaire

01:25:32
Another innovation: printing the crease pattern as perforated dotted lines on a laser plotter.

01:26:04
The dotted lines then enable Robert to pre-fold the pattern. Through Robert and his software like his "Tree-maker" », mathematicians are muscling-into the world of origami like never before.

01:26:18

Robert Lang

Math has been such an important part of how I approach origami. I'm sure I would've still enjoyed it, I enjoyed it for the years before I applied math to it. But having mathematics available to this, made it much, much more interesting.

Well I started origami when I was about six. And I encountered some instructions in a book, and just coincidentally enough, one of them was for a spider. Considerably easier spider than this one, but I was hooked. And I think the thing that hooked me was the idea that all you needed was a sheet of paper and knowledge. The knowledge of how to fold. Nothing else. You didn't need extra parts that could wear out. Just paper and paper was available anywhere.

This spider shares something in common with most other origami figures. Even going back to that very first figure I folded. This is still after all this manipulation, an uncouth square of paper.

Commentaire

01:27:57

Robert Lang led the way by creating the first folding algorithms and computer tools that make it considerably faster to master this incredibly complex art… however, the thirst for greater mastery is pushing the envelope even further… towards the Holy Grail of origami: the ability to fold anything!

That is what the designer and origami engineer, Tomohiro Tachi, is seeking to do. Together with Erik Demaine, he is developing a system called "Origamizer", the first software capable of creating even the most complex 3D crease patterns. For Tomohiro, the Holy Grail is… the teapot!

01:28:35

Tomohiro Tachi

So the objective was to make any polyhedral surface out of a sheet of paper. And I tried to make a geometric way of constructing that, which is something like this. So this one is folded from a sheet of paper and I folded this in 2006.

The teapot is well known for computer graphics community. And it is kind of a test model.

This took a lot of time for me to design but as I knew that once I folded this one, I knew that it is possible to make almost anything.

01:29:17

Erik Demaine IN

And let's run Origamizer...

Commentaire

01:29:20
Erik describes the basic principle using 3 squares, which constitute the simplest volume… like half a cube. The challenge is to get the computer to create a 2D crease pattern on a sheet of paper so that when you fold the paper you only see the desired shape, any excess paper is hidden.

01:29:40
Erik Demaine
So, I've printed that pattern out. It looks like this. I changed the colours a little bit. So, we've got the three squares and we've got some creases to get rid of the stuff in between.

So let's do some folding.

01:29:56
Erik Demaine
The main idea is pretty simple. We're folding along these bisectors to bring two edges of the two squares together. So, something like this. So, the two squares are good. Getting all three at once, though, that's a little trickier.

Yes, so we made exactly what we wanted. I guess I had some extra material out here. I can just fold that away. That's not too bad.

Commentaire

01:30:31
The algorithms that Erik and Tomohiro are developing are actually material organising tools. One should be able to create a 3D shape from any flat surface. One material, one piece, one process: folding. It's a whole new way of manufacturing things, almost nature's approach and it offers infinite possibilities!

01:30:57
Tomohiro Tachi
Erik and I will prove that any shape is foldable from a sheet of paper. Yeah, I am, we are very excited about that.

Commentaire

01:31:12
Erik and Tomohiro are not far from their goal! Meanwhile, thanks to their work and the work of others before them, such as Robert Lang, origami-inspired objects are already beginning to appear around us: airbags in our cars, decorations, packaging, architecture, fashion… They could prove useful in every domain, even in improbable areas such as the Starshade project; a NASA programme for observing exoplanets.

By deploying a disc 35 metres wide, the glare of the stars around which exoplanets gravitate can be blocked, thus improving their detection with space telescopes…

01:32:00
Erik Demaine
In the last few years there's been a lot more excitement about the engineering and science applications of origami. You can make practical structures that fundamentally change their shape. Either going from a flat thing or very tightly folded thing and being able to deploy into different sizes or completely change their structure, changing from one shape to another by folding. Folding gives you a way to think about shape transformation. Like transformers, which I grew up with. This may be one of the motivations.

Commentaire

01:32:39
The challenge of mastering the complexities of folding is burgeoning. Yet the origami revolution is not so far as widespread as you would expect… Apart from a few everyday objects and extraordinary prototypes like this emergency shelter invented by Tomohiro, will the concept of origami ever really be as pervasive in our societies as it already is in nature?

01:33:07
Yves Klett of the Stuttgart Institute of Aeronautic believes so and he is doing his best to bring origami to the industrial world…

01:33:16
Yves Klett
Wir waren auf der Suche nach neuen Kernmaterialien für Sandwich-Anwendungen, für Leichtbauanwendungen. Und wir fanden diese Strukturen, die vom Origami inspiriert sind. Und es hat sich gezeigt, dass diese Strukturen sich hervorragend eignen, um Kernstrukturen für Sandwich-Anwendungen zu bauen. Eine typische Sandwich-Konstruktion sieht so aus: wir haben zwei Deckschichten und wir haben in diesem Fall einen gefalteten Kern dazwischen. Und was wir gewinnen, ist eine enorme Stabilität. Wir haben eine sehr leichte Struktur, die sehr hohe Lasten ertragen kann. Also ich kann jetzt dieses Teil hier gar nicht mehr zerdrücken, während der Kern an sich relativ wenig Stabilität aufweisen würde. In der Kombination bekommen wir aber sehr, sehr leichte und sehr leistungsfähige Bauteile. Aber clever gesetzte Falten kann man aus einem einfachen Stück Papier eine Struktur machen, die mehrere Tonnen aushalten kann.

It was whilst looking for new materials to develop what we call "sandwich" applications, i.e., lightweight applications, that we discovered origami-inspired structures, which are ideal for “sandwich” applications. A “sandwich” construction looks like this: there are two outer layers and, in this case, there is a folded core between them. The great advantage of this is improved solidity. We now have a lightweight structure that can withstand very high loads. I can’t crush this side even though the core itself may look fragile. Such a combination gives us a very light-weight yet strong component.

With a few clever folds, you can design a structure that can withstand several tonnes from a simple piece of paper.

01:34:37
Yves Klett
Das Experiment war erfolgreich. Wir konnten mit dem Auto auf wenige Gramm Papier fahren. Und damit haben wir gezeigt, dass diese Idee, Origami für Leichtbaustrukturen zu verwenden auch wirklich funktioniert. Da freuen wir uns. Und es ist erstaunlich, was man mit wenigen Gramm Papier alles ausrichten kann. Diese Struktur kann auch noch höhere Lasten ertragen.

Our experiment worked. We were able to drive a car over paper weighing barely a few grams. That demonstrates that using origami for lightweight constructions really works. It's truly amazing what can be done with paper weighing just a few grams, knowing that such a structure can withstand even much more weight.

Commentaire

01:34:57
By enabling us to build lightweight, durable objects, origami could indeed play a large role in innovative technologies. However it has one major manufacturing drawback; the folding still has to be done by human hands! Yves Klett is well aware of this but maybe he has an answer, which he is not yet ready to reveal entirely...

01:35:19
Yves Klett
Ein interessanter Aspekt ist natürlich, dass man mit Origami theoretische sehr, sehr viel Verwirklichen kann. Ich kann sehr viele verschiedene Strukturen falten. Aber nicht alle dieser Strukturen eignen sich jetzt für den industriellen Einsatz. (sondern) da brauche ich eine Struktur, die immer aus den gleichen Elementen aus wiederholten Elementen besteht, die ich auch automatisiert herstellen kann. Und deswegen arbeiten wir mit solchen tesselations, die sehr regelmäßig sind. Die bestehen aus sehr einfachen Einheitszellen, sehr einfachen Elementen, die dann immer und immer wieder wiederholt werden. Und nur so kann man dann auch automatisiert gewährleisten, dass wir die Strukturen effizient herstellen können.

What is interesting about origami is that in theory, you could make anything you want. Just imagine the infinite number of structures you could create. However, these structures are not yet suitable for industrial use. Automation requires some degree of uniformity. I cannot just produce folds willy-nilly; I need a structure that consists of similar items; recurring items that can be manufactured automatically. This is why we work with regular frames. They consist of single unit cells that can be repeated again and again. This is the only way the structures can be produced efficiently and automatically.

01:36:28
Yves Klett
Und genau da stehen wir jetzt. Wir haben Prototypenanlagen, die automatisch falten und jetzt arbeiten wir zusammen mit Industriepartnern daran, daraus Produkte zu entwickeln.

This is where we are today. We have developed prototype machines that can do the folding process automatically. We are now working on developing products in partnership with industrial partners.

Commentaire

01:36:45
So are we going to be able to fold everything at industrial level, if necessary? Are we as efficient as nature when it comes to folding? Maybe not quite. Nature still has the upper hand, in that it can both assemble and fold automatically – we can't quite match that yet!

01:37:27
Robert Wood Student IN
Okay, there is a flight in three, two, one... go!

Commentaire

01:37:39
A robotics team at Harvard University headed by Robert Wood is passionate about nature's ability to assemble shapes automatically by folding. Robert Wood is convinced that nature is actually showing us how to build things more freely in small scale. This could revolutionise robotics completely!

01:38:01
Robert Wood
If I think about an example of assembling a car, you know, however many thousands or tens of thousands of components go into that.

Now if I want to assemble something maybe not that complicated but similar complexity down on the scale of an insect or even smaller you're not going to be able to do the sort of nuts and bolts approach. You're not going to be able to hand assemble hundreds or thousands of components together.

On the other hand if you can do things that are self-assembled and in our case we use folding at the self-assembly means than it allows you to do things faster, more precise.

Commentaire

01:38:44
Robert Wood encourages his team to bend the rules of origami. He asks them to make a few cuts and to stack the folds. This increases the possibilities tenfold and soon, just as nature gradually transforms a flower bud into a bloom, a mini robot will be able to deploy by simply changing the temperature or sending an electric current... the method used may differ from what occurs in nature but the concept is very similar.

01:39:12
Robert Wood
Now that we have the ability to manufacture small articulated actuated things like the RoboBee we can apply these techniques to other areas: Consumer electronics is one, surgical robotics is another. Places where you'd want various small featured sizes or cheap disposable things with you know any arbitrary material, rapid prototyping etc. This is what really motivates us, is these sorts of application areas.

Commentaire

01:39:42
By trying to automate the folding process, Robert Wood is bringing robotics and biomimetics together. A recent lab creation is proof of that. Cut from a single sheet of polymer, a robot automatically folds itself using hinges activated by increases in temperature. When it reaches its final shape, its on-board motors are automatically activated and then its limbs and… the robot is born.

When paraded around the world, at least via the internet, the little robot astounded the research community…

01:40:15
Nature builds by folding and, thanks to origami, we are learning to do likewise. It is early days yet, but it is clear that we are already making good progress.

Commentaire

01:40:29

However, the biologist Ivan Huc believes that by taking inspiration from nature's automatic folding process, one can go much further than imagined because although we know that nature builds by folding, we still don't realize just how far it goes and to what scale!

Ivan is not just anybody; he is head of the European Chemistry and Biology Institute based in Pessac, near Bordeaux. Before going to his lab, he popped in to get something to show us how life is a world of folds!

01:41:02
It may not be evident but Ivan believes that a series of hinges hooked up together can provide us with a simple example. And speaking of the essential mechanisms of life...

01:41:18
Yes, the molecules of life, nucleic acids like DNA, which carry our genes no less. And proteins, these linchpins of our organism, are masterpieces of 3D folds! And there are very good reasons for that...

01:41:36
Yvan Huc
Living things can be described as a series of organised systems. Evolving in a natural environment that is chaotic, living things organise themselves automatically and this process of self-organization starts at molecular level. The smallest organised objects we can see in living things are folded proteins and nucleic acids, also with their folded patterns.

Commentaire

01:42:05
The centre of our cells is very chaotic because there is a lot of frenetic movement at molecular level. Whereas, for a living thing to work well, it needs stability. It restores stability by self-assembling folded things. The proteins studied by Ivan Huc are the perfect example.

The proteins in the cell are assembled from elements clinging to each other, like the chain of hinges created by Ivan. Incredible small origamis, folded not from a sheet but from a one-dimensional strand.

01:42:44
Yvan Huc
That is how the whole is assembled.

Commentaire

01:42:49

Since each hinge is connected at an ideal angle, the protein can twist and turn until it reaches a stable pattern.

01:42:59
The 1-dimensional strand then becomes a 3-dimensional, stable object able to withstand the chaos of the cellular world!

01:43:07
There are as many different folded shapes as there are proteins, each with its own vital function of our metabolism; e.g., respiration with haemoglobin that binds with oxygen.

01:43:21
Yvan Huc
So, the shape dictates the function in living things, which implies that if the shape is not folded correctly, it won't work properly. Many known diseases are caused by fold defects.

Commentaire

01:43:35
Indeed, just one defect in the haemoglobin fold and the red blood cells will not be the right shape and thus, they will not carry enough oxygen, which would lead to the dangerous condition called sickle cell anaemia.

01:43:50
Therefore, understanding protein folds is a major concern of contemporary research. Knowing how to identify and repair fold defects would be a huge step forward. But there are so many possible pattern combinations that researchers are still a long way from nailing it. Nevertheless, they can still learn the principle!

The idea is to mimic the auto-assembling process of a protein but limiting ourselves to simple shapes; shapes whose crease patterns can be created and executed in a controlled manner.

01:44:23
This is the Foldamer project, a term derived from "fold" and "mer" a unit in chemistry - as in "polymer" - many links, so to speak.

01:44:34
Yvan Huc
So here we are in the process of assembling foldamers. The operation involves activating the links one at a time and then attaching them to the chain. This way, we can have links that are all different from each other. This is mostly a manual process; it actually has to be done by hand. However, the properties of the objects created are extremely sophisticated.

Commentaire

01:45:02
With foldamers, the concept of origami enables us to create new molecules with specific functions, e.g., molecules to deliver drugs to ailing cells or, as in this example, to detect unwanted or even toxic substances. The propeller-shaped foldamer here opens up to trap a molecule of the analyte and then closes. The foldamer emits a fluorescent light to signify that it has captured the analyte.

01:45:35
Foldamers are revealing new tools inspired from the system of folds operating at minute scales.

01:45:54
Did we expect to witness the concept of origami operating at such a small scale?
Folding is at the heart of life; in some ways, it is a fundamental mechanism!

01:46:06
And at whatever scale...

Commentaire: start of Neyrinck sequence

01:46:17
In Baltimore on the East Coast of the United States, an unexpected origami application is being developed.

01:46:28
An astrophysicist from the Johns Hopkins University, Mark Neyrinck, is developing a new model for explaining the structures of the universe.

01:46:44
One of the great challenges of contemporary astrophysics lies in creating models that represent the structure of the universe and the different types of matter that it is made of. There are so-called "ordinary" matter, which responds to the classic laws of physics and what we, the suns and planets are made of. There is also the even more abundant, so-called enigmatic "dark" matter that we cannot see... It is this dark matter that makes Mark Neyrinck tick...

01:47:15
Mark NEYRICK
The dark matter started to accumulate into clumps almost immediately after the big bang and we wouldn’t have as much structures as we see in the universe today if there hadn’t been this dark matter. It started to clump immediately.
The normal matter started to form structures based on the ground work, the skeleton that the dark matter laid down right away. So the dark matter is really the basis of

understanding of the structures that we see today. Except deeply inside galaxies where ordinary matter of course plays a huge role.

Commentaire

01:47:54
Mark is trying to model the network of dark matter in the universe by using the filaments woven into the cosmic vastness and its points of overlap; nodes in which ordinary matter is concentrated. Mark uses geometric shapes to represent the dynamics of dark matter filaments at these nodes. In this case he uses superimposed polygons. A triangular structure appears at the centre. However, inspired by origami, Mark has discovered that twist folds are ideal for representing the mechanism of these nodes.

01:48:30
Mark NEYRICK
So in a twist fold, you have small polygons. Let's say a triangle. So here we have a triangle. Going from the unfolded to the folded state entails twisting that triangle.
Even though this is a dark matter structure, it accretes regular matter towards it.

So the galaxy would form here. So that is pretty simple. I think it is engaging, because you can actually form a model of the universe. You can fold your own universe. It's a strong approximation that the universe forms like an origami model. The way that the elements of the cosmic web are spinning are very explicit in this model.

We see in the universe that neighbouring galaxies tend to be rotating in the same direction and that actually relates to this origami model.

Commentaire
01:49:44

Mark asked his students to make a paper model of his latest work. The crease pattern represents the organisation of dark matter in a portion of space.

01:50:04
The points represent the galaxies while the clumps of twisted folds represent the dark matter and, therefore, a greater number of galaxies. The model also accurately reproduces the direction of rotation of the galaxies and how they interact with each other!

01:50:19
Mark Neyrick IN
Leave some slack in the paper because it's gonna contract.

Commentaire

01:50:28
Mark is delighted with the relevance of his origami model. In a field where scientific abstraction makes comprehension difficult, origami models bring a degree of concreteness and beauty. It captivates us and enables us to dream a great deal more easily than from just staring at lines of equations.

Commentaire: conclusion

01:50:52
Origami provides us with fundamental keys to understanding the universe and the vastness of space right down to the heart of our cells.

01:51:04
This journey started by uniquely combining art and science. How could one imagine that simply folding a flat surface could help us discover a universal code of Nature? Yet, from whatever level we observe them, the system of folds is at work and it is helping us to understand how nature is structured and organised and how living things develop and survive.

01:51:33
As we unveil this world in folds, we are being inspired to create and build like nature…

01:51:38
The End