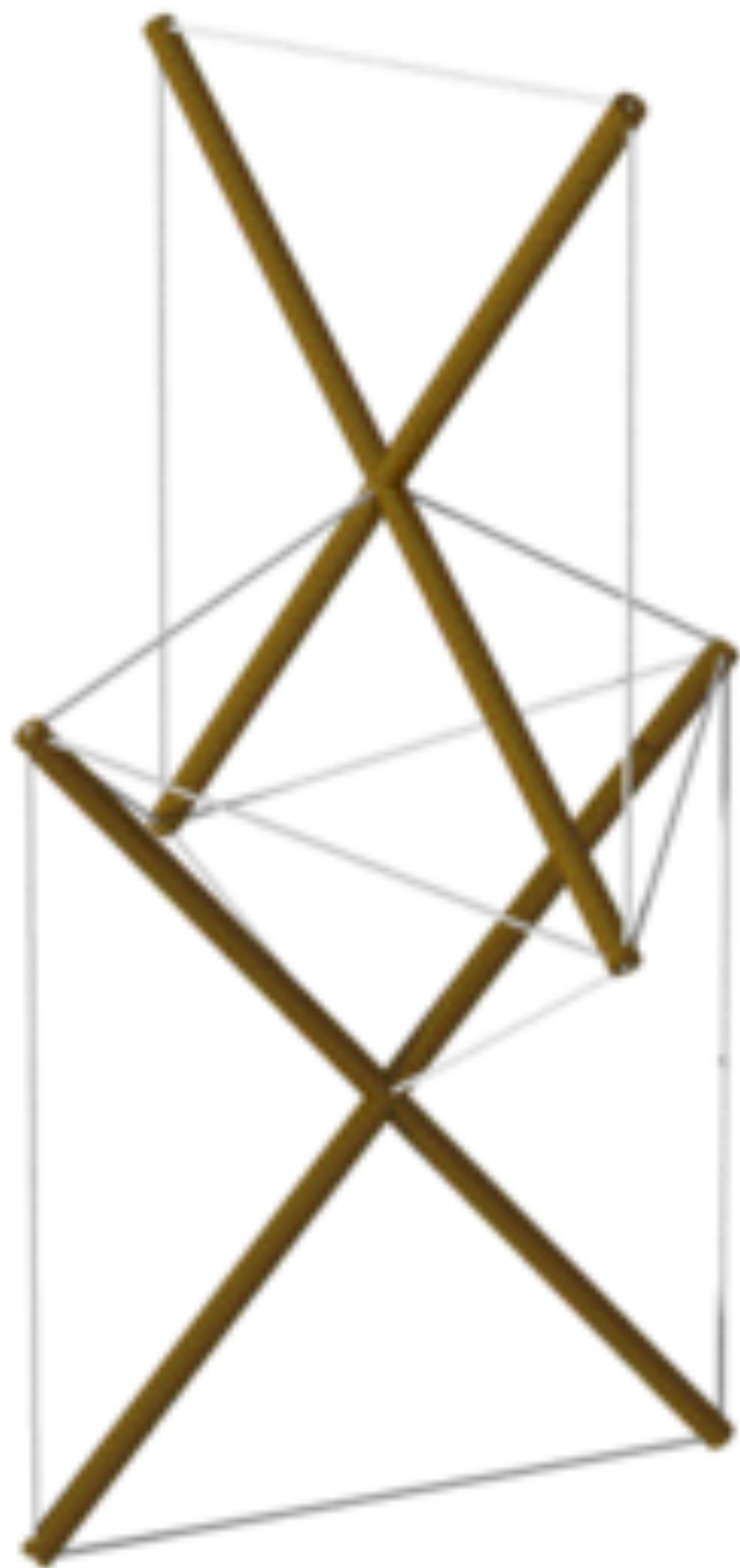


TENSEGRITY

The Simplicity of Living Cells

TENSEGRITY

- Tensegrity as a word is a mixing of tensional and integrity. It comes to us from R. Buckminster Fuller and is applied in the architectural and engineering world.
- Fuller began developing his vision in the 1920's, at a time when many were exploring new directions in design and architecture. But it was his student, the sculptor Kenneth Snelson, who, in 1949, created the first structure to be defined as a "tensegrity". Using two X-shaped wooden struts suspended in air by a taut nylon cable, Snelson captured the defining features of tensegrity.



TENSEGRITY PROPERTIES

- **Pervasive tension and a separation of rigid elements.** In Snelson's now iconic structure, the compression-resistant struts do not touch but instead are individually lifted, each embraced and interconnected by a system of continuously tensed cables, a condition that Snelson and Fuller called "continuous tension, discontinuous compression."
- **Stable.** Though ethereal in appearance—its wooden Xs appear almost to float—Snelson's sculpture is remarkably stable, despite its minimal use of rigid elements. This stability is due to the fact that tensile and compressive components are, at all times, in mechanical equilibrium.

TENSEGRITY PROPERTIES

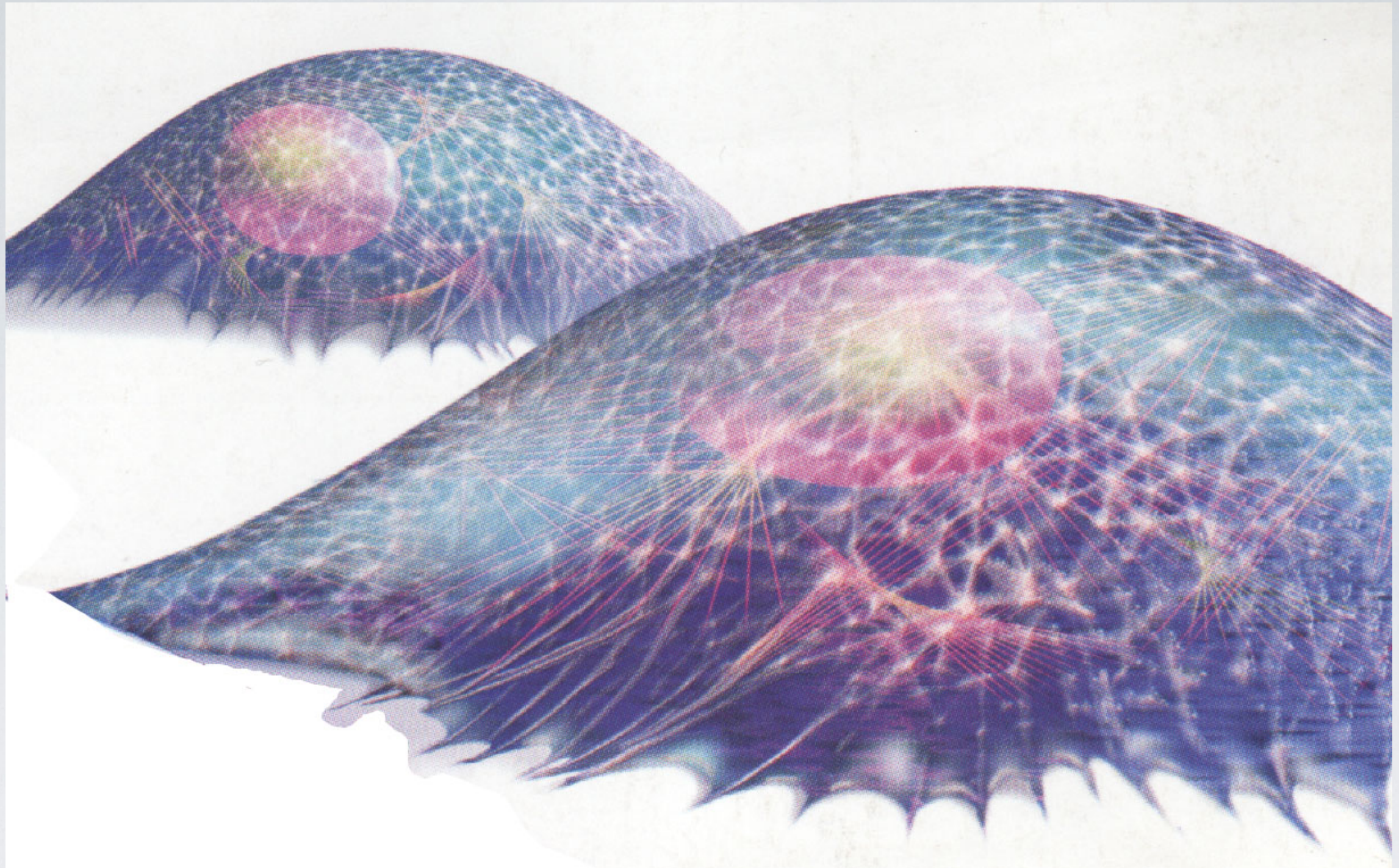
- **Prestressed.** This mechanical equilibrium results from the way the compression and tensile components interact to bring out each other's essential nature: the cables pull in on both ends of the struts, while the struts push out and stretch the cables. The result is that each element in a tensegrity structure is already stressed—the compression elements are already compressed, the tensile elements already tensed—and they are stressed by each other, a condition known as "self-stress" or “prestress.”
- **Resilient.** While they are stabilized by prestress, tensegrity structures are also exquisitely responsive to outside perturbation. Their components immediately reorient when the structure is deformed, and they do so reversibly and without breaking.

TENSEGRITY PROPERTIES

- **Globally Integrated.** Because the components are so intimately interconnected, what is felt by one is felt by all, producing a truly holistic structure.
- **Modular.** Though complete on its own, a tensegrity structure can combine with other such structures to form a larger tensegrity system. In these systems, individual tensegrity units can be disrupted without compromising overall system integrity.
- **Hierarchical.** In fact, smaller tensegrity structures may function as compressive or tensile components in a larger tensegrity system, which in turn may perform a similar function in still larger systems.

TENSEGRITY

- Donald Ingber, a researcher at the Harvard Medical School has proposed a model using the tensegrity concept to describe cellular architecture.
- With this model, the complexity of the cell, the body and how it works becomes more simple.



Living cells contain a cytoskeleton that generates and transfers tensional forces in a way best comprehended by a “tensegrity” model.

Changes in the cytoskeletal force balance alter tissue homeostasis.

-Ingber

TENSEGRITY

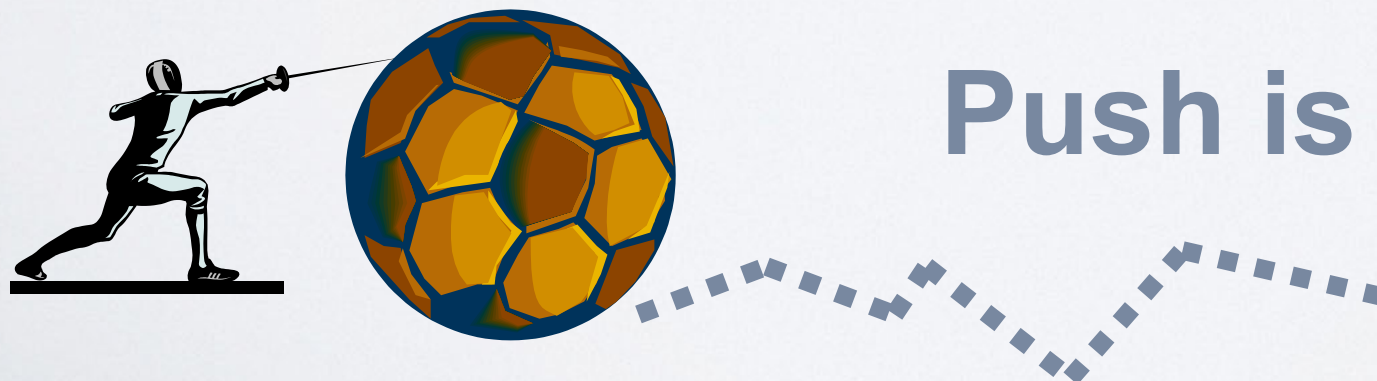
- Presentation agenda:
 - Tensegrity principles.
 - Comparison with the old model.
 - Examples in the world and body.
- Application to Osteopathy.

TENSEGRITY

- Tensegrity is the result when push and pull have a win-win relationship.
- Buckminster Fuller explained that push and pull were not opposites, but compliments – one could not be found without the other.
- He stated that in tensegrity pull is continuous/convergent and push is discontinuous/divergent.

TENSEGRITY

- Imagine trying to push the soccer ball in the image below with the foil.
- The ball would always move away from the push, but it could roll in any direction.

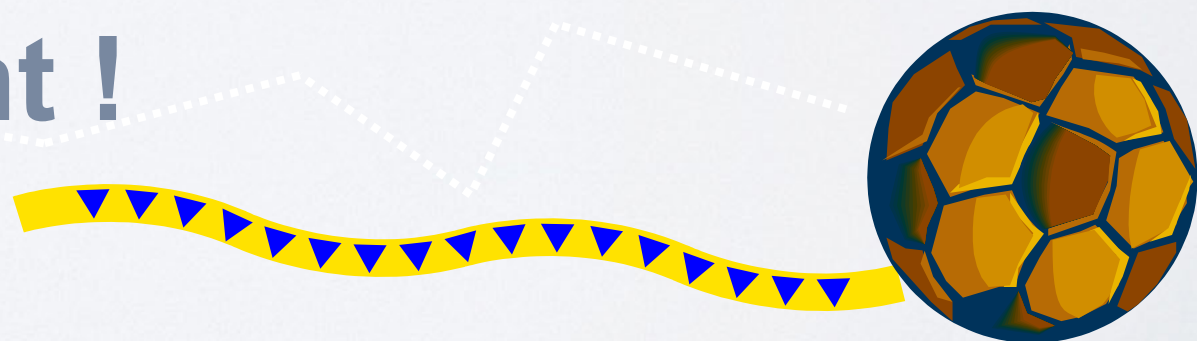


Push is divergent !

TENSEGRITY

- Now imagine the same ball with a string attached.
- No matter what forces acted upon the ball, the string would always tend to bring the ball towards you.

Pull is convergent !



TENSEGRITY

- Another example is a wrecker towing a car.
- The car wants to follow the wrecker where ever it goes – convergent pull.



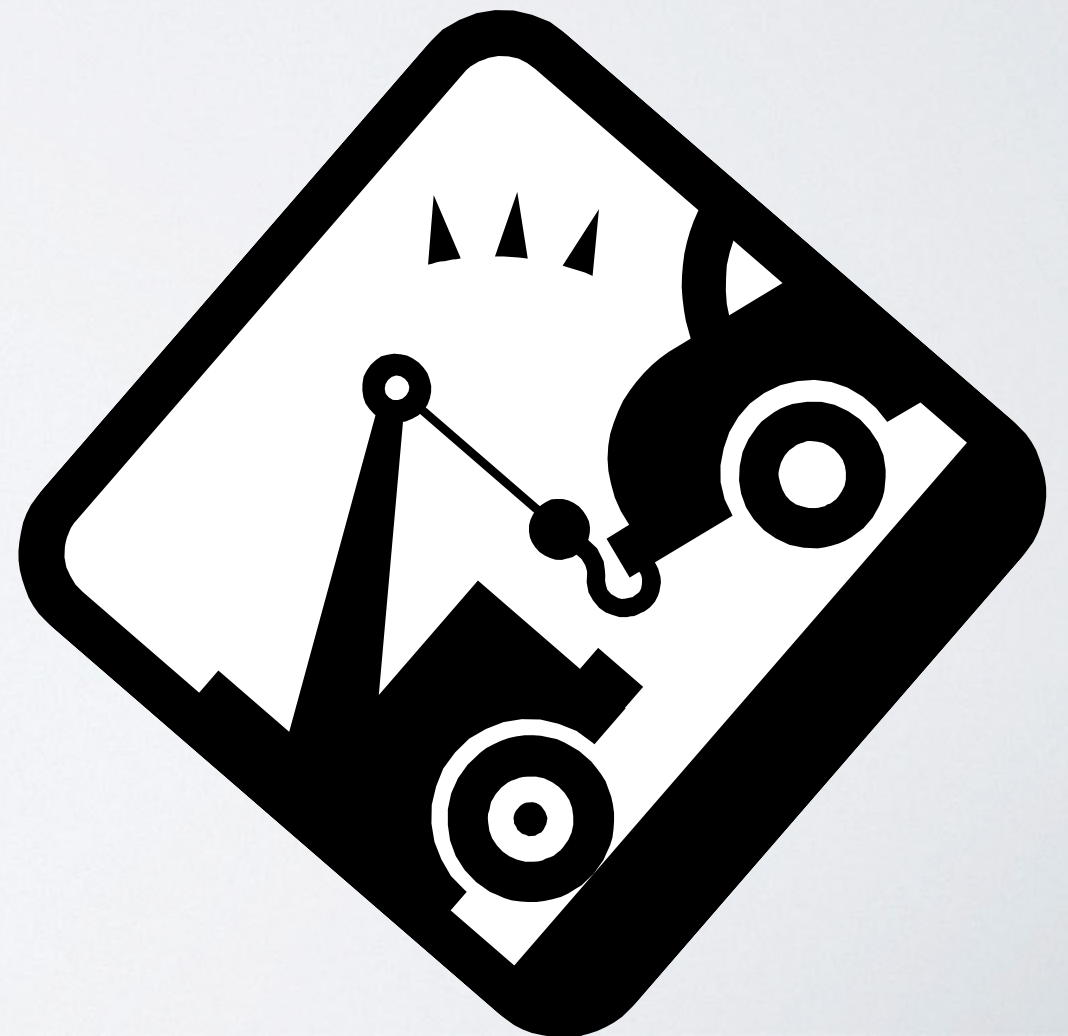
TENSEGRITY

- This is even more pronounced when the wrecker is going uphill.
- The car will track in a very straight line – convergent pull is predominant.



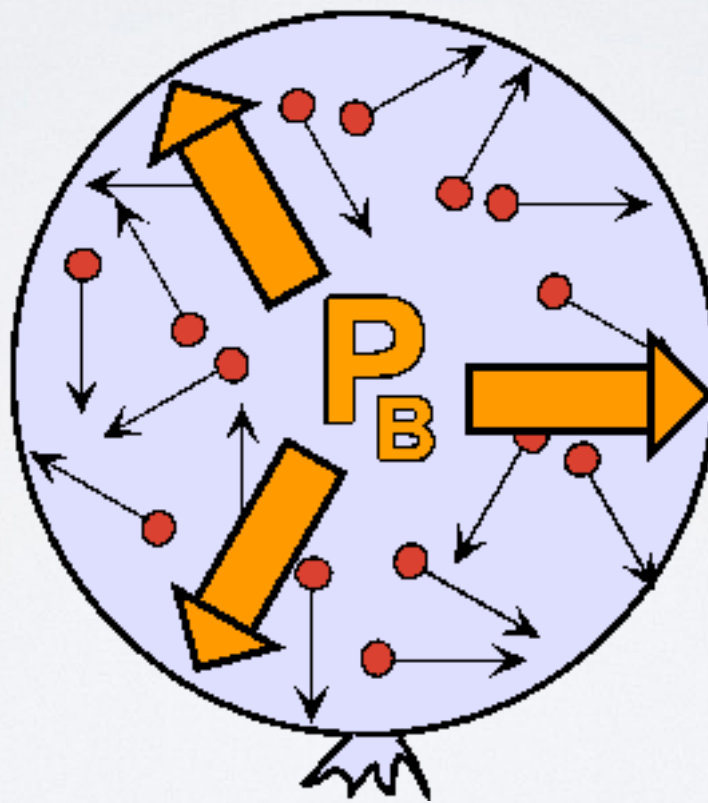
TENSEGRITY

- When the wrecker is going downhill things change.
- The car begins to push the wrecker and cause sway – divergent push.
- Acceleration will counter the push.



TENSEGRITY

- In a balloon the air molecules inside are exerting a discontinuous push against the skin of the balloon, which is constantly trying to pull itself smaller.

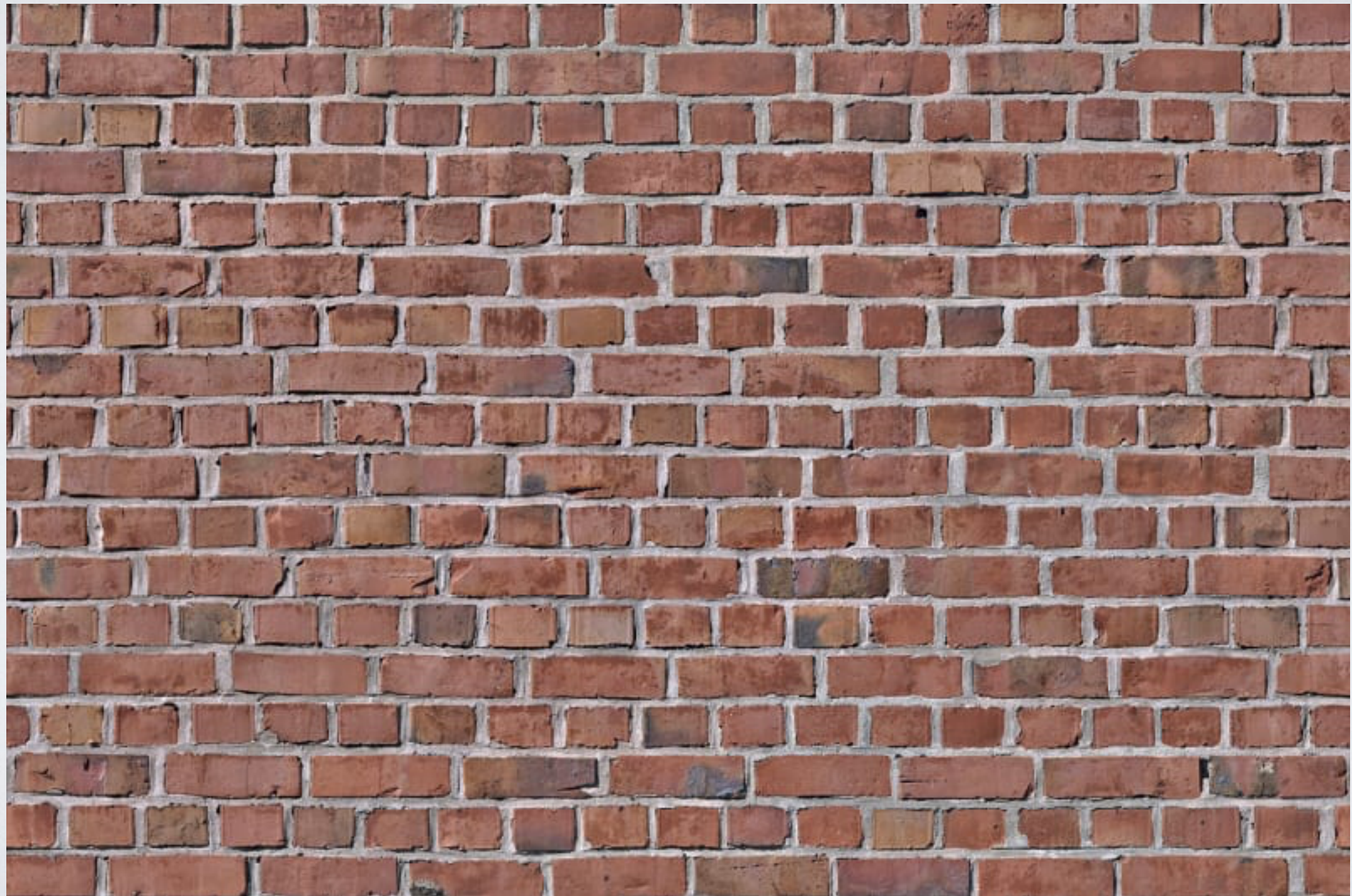


- This balance of pull and push makes any tensegrity structure inherently strong and stable. The larger the system the stronger it is.

TENSEGRITY

- The conventional model of the world is based on compressional continuity.
 - A brick building is supported by gravity, its walls, floor and cross members.
 - The height and shape of these buildings is limited by the shape of the bricks, their weight capacity, the adhesiveness of the mortar, etc.
 - And if the foundation shifts, the building settles, leans or crumbles.
 - And if we remove the effects of gravity all bets are off...

TENSEGRITY



TENSEGRITY

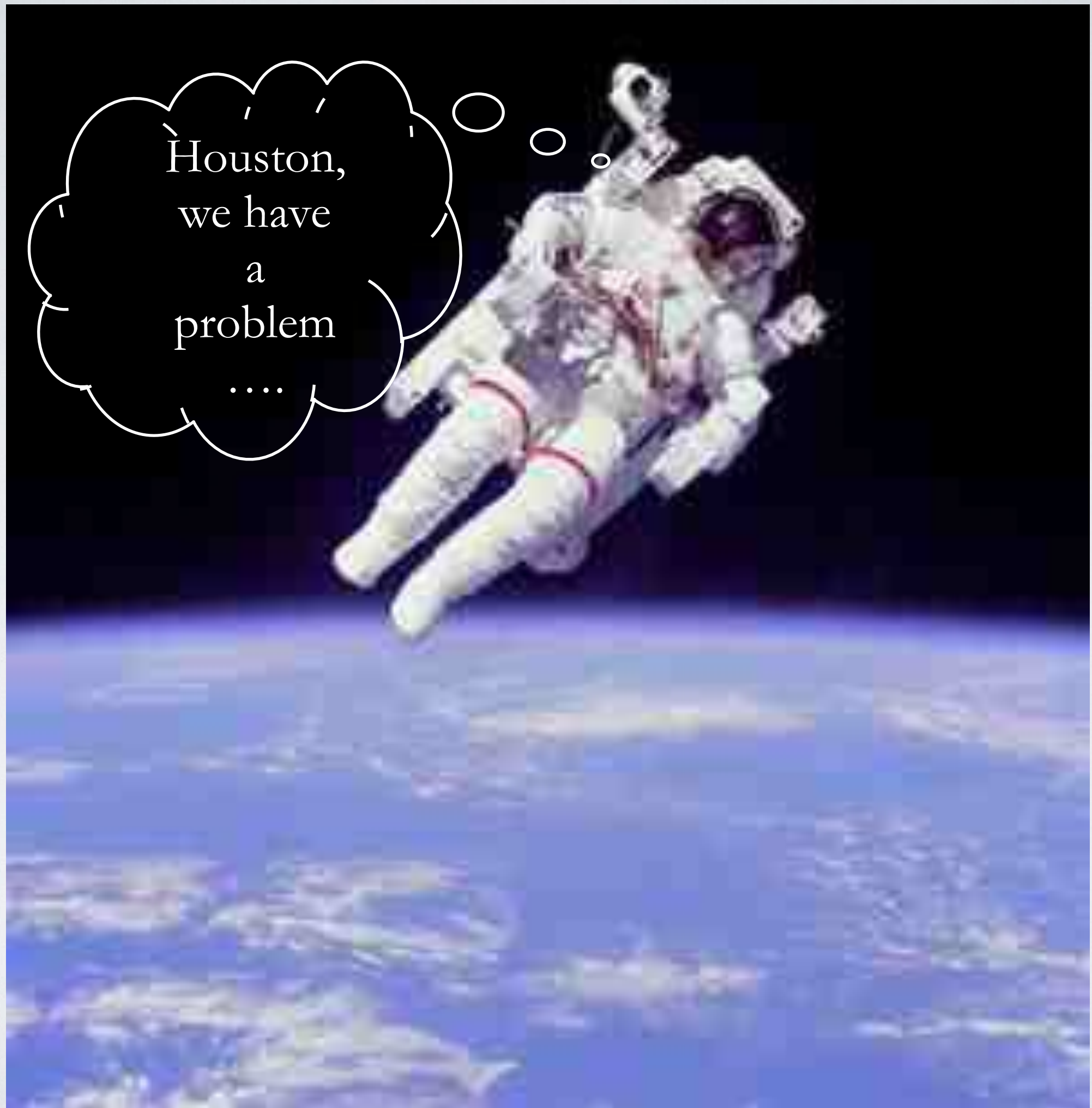
- If we use the old model to view the human body, the human spine is a stack of blocks.
- It transfers the weight of the body down into the sacrum.
- The sacrum transfers its load to the ilia, the ilia to the femurs, ... and so on.
- This model hinges around the gravity concept and that the sacrum acts like a “wedge” between the hips, locking itself in for stability.

TENSEGRITY

- It is based upon Newtonian and Galilean mechanical laws.
- If we follow these laws and apply them to biological systems:
 - The human bony spine would bend with less than the weight of the head on top of it.
 - Vertebral bodies would crush under the leverage of a fly rod held in a hand.
 - Animals larger than a lion would continually break their bones.
 - Urinary bladders and pregnant uteri would burst when full.
 - With each heartbeat, arteries would lengthen enough to crowd the brain out of the skull

Houston,
we have
a
problem

....



TENSEGRITY

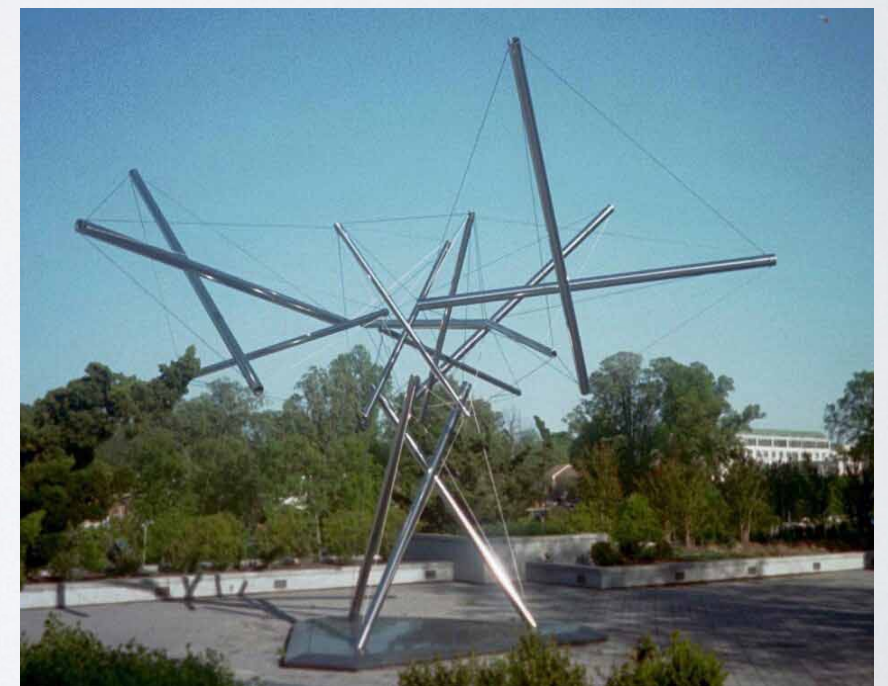
- Tensegrity differs from the conventional concept of compressional continuity in the following ways:

Tensegrity	Compressional Continuity
▪ Continuous ▪ Balanced ▪ Integrated ▪ (osteopathy)	▪ Discontinuous ▪ Unbalanced ▪ Seperate

TENSEGRITY

- During the gestational period and for the first year or so of life, the human spine functions as an architectural “beam” with rigid segments connected by flexible connective tissue that “float” the segments in space.

- This is a tensegrity structure.



TENSEGRITY

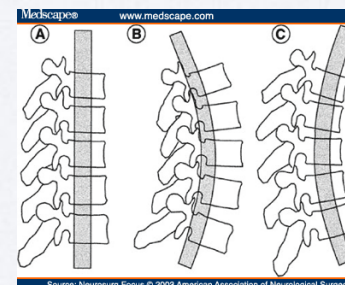
- But defining the spine as a simple “beam” doesn’t really fit either.



- We think of a beam as a rigid structure, perhaps with some flexibility – like the wing of a commercial airliner.



- But the spine flexes much more than that when we move forward or even bend backward.



TENSEGRITY

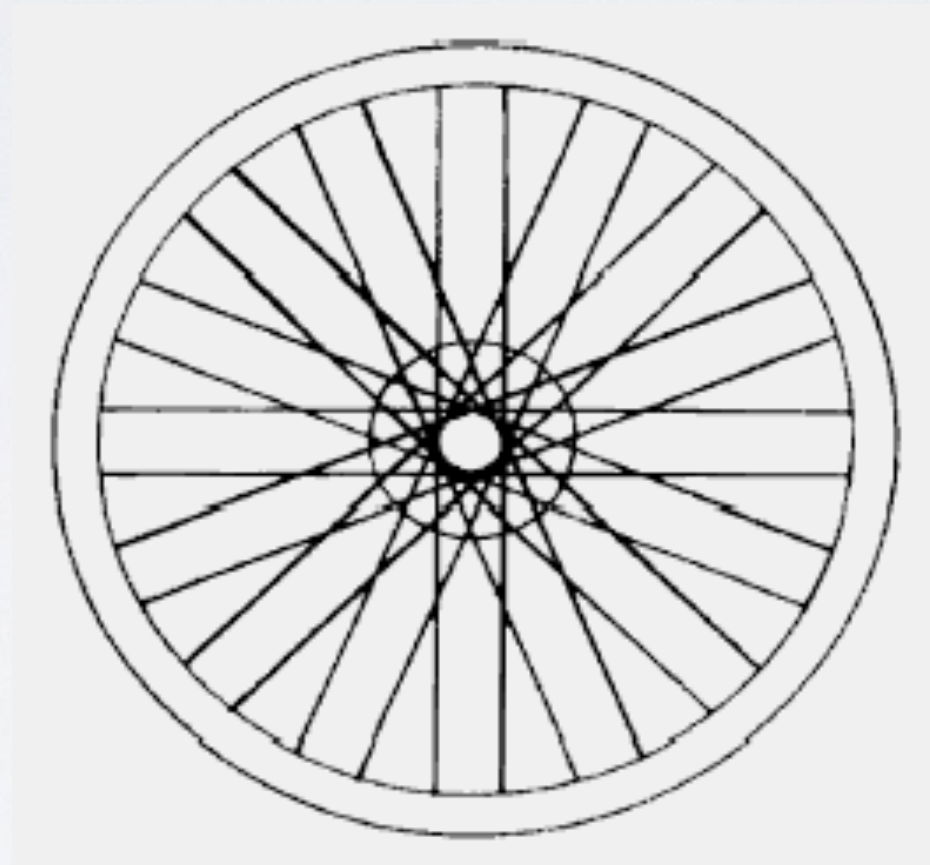
- If we adopt the conceptual model that the spine as we advance in age does not really change much in design from birth, then we can imagine it as a series of rigid bodies (the vertebrae) that are held together by a series of interconnecting, flexible tensioning elements (the muscles and ligaments) with some flexible frictionless articulations in between (the intervertebral discs).
- And we have a tensegrity structure!

TENSEGRITY

To understand tensegrity structure more fully let's back up and look at a simple model.

TENSEGRITY

- Let's look at a bicycle wheel.



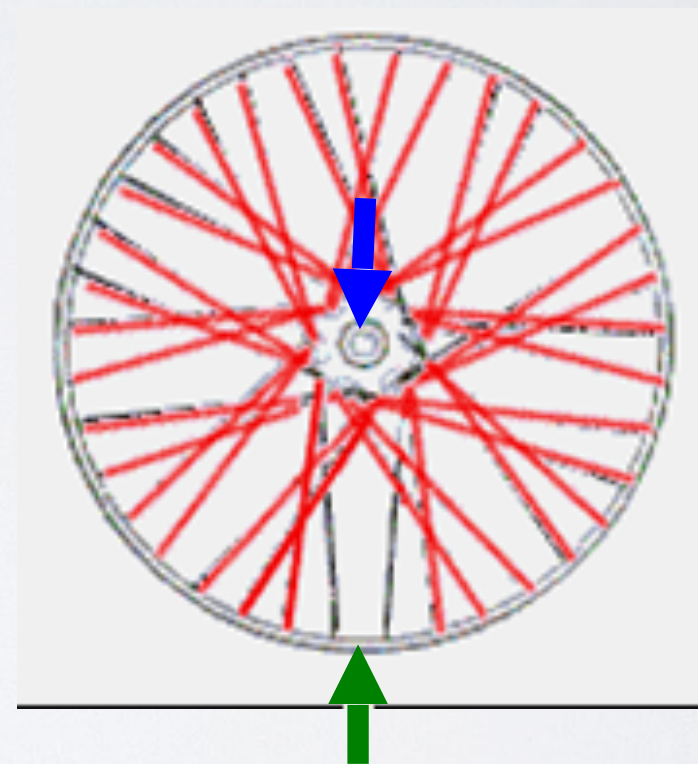
TENSEGRITY

- In its basic form a bicycle wheel is a rim, some spokes and a hub (it takes a minimum of 12 spokes to make a wheel with a fixed hub).
- Once the wheel is built, the compressive load applied to the hub by the bicycle and rider is transferred to the rim solely through tension.
- The compressive load is distributed evenly around the rim so that no one place has an excessive load in a well built wheel.

TENSEGRITY

- The compressive units of the wheel behave in a counterintuitive way.

When a load is placed on the hub, the downward force actually **UNLOADS** the spokes and the rim where it meets the ground. All of the other spokes evenly distribute the stress!



No Weight!

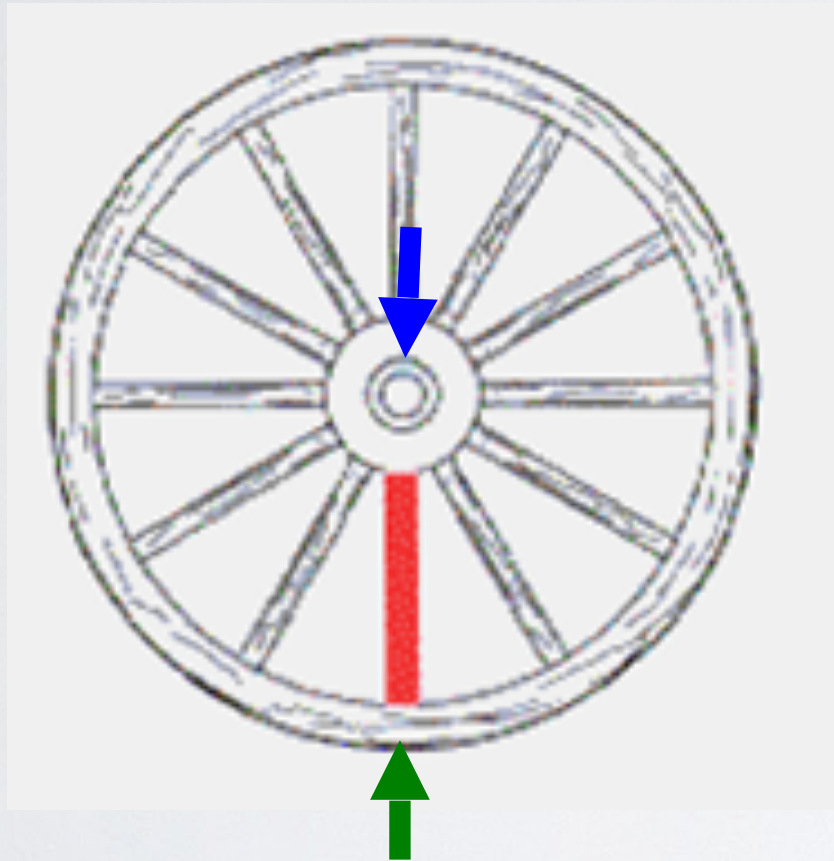
This is Tensegrity!

TENSEGRITY

- When the wheel is rolling, compression is discontinuous.
- While the tension of the spokes on the rim is continuous.
- Tensegrity structures transmit loads through tension and compression only!
 - Because these structures are 3 dimensional, there are no bending or shearing forces involved.



TENSEGRITY



All the Weight!

This is a stark contrast to the old wagon wheel design (also used in most car wheels) that places all of the weight of the hub always on the lowest spoke. These designs must be more robust to handle the same weight as a tensegrity design.

TENSEGRITY

- Let's look at a few more tensegrity structures:

The tennis racket transmits the compression force of the racket frame to the ball through the strings.



TENSEGRITY

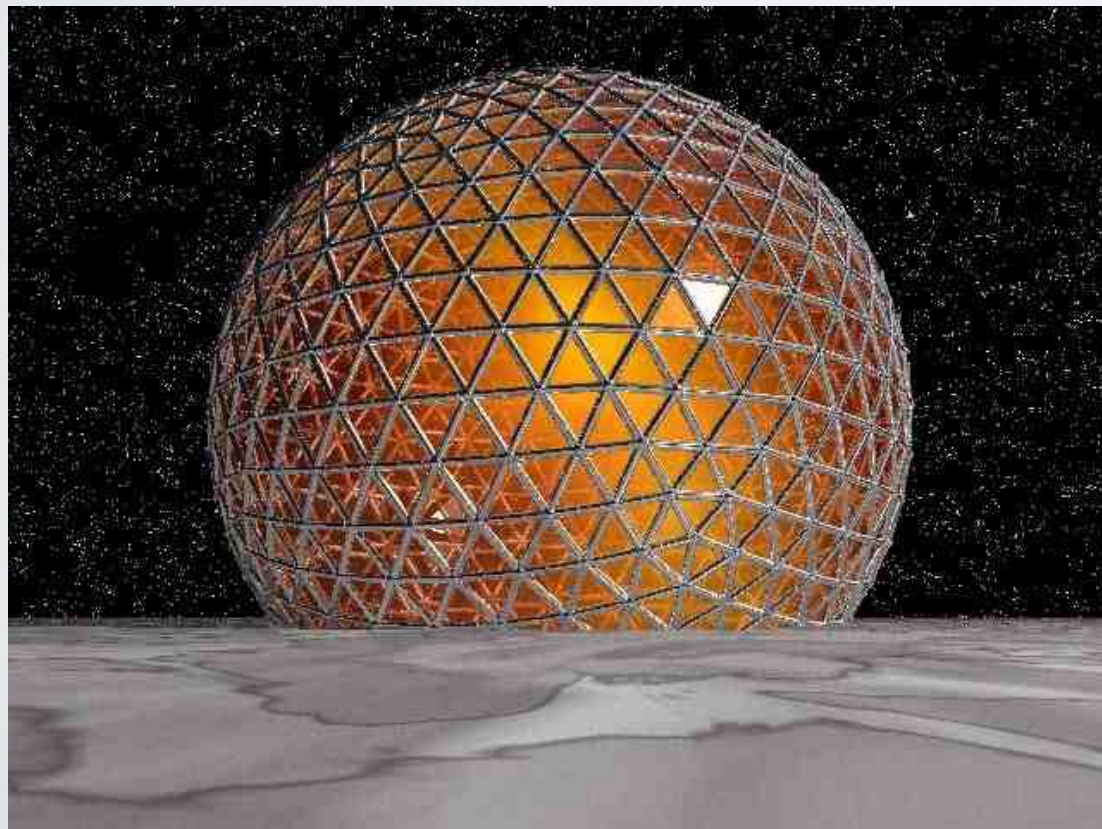
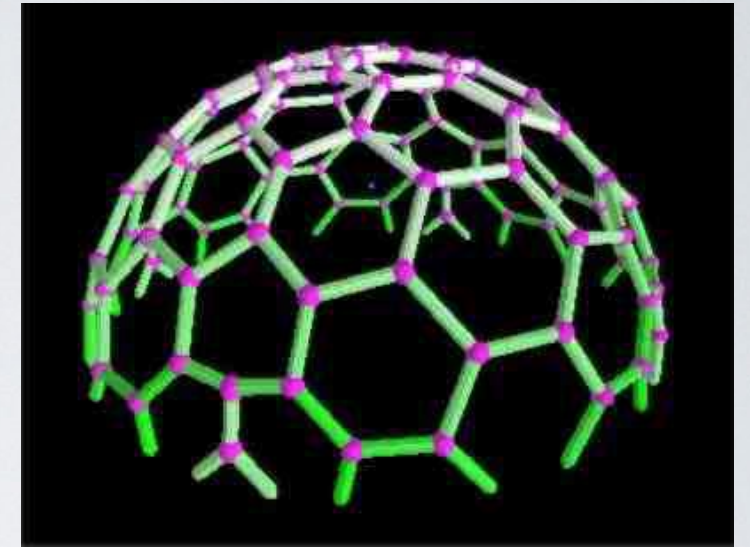


Same principle with snow shoes



TENSEGRITY

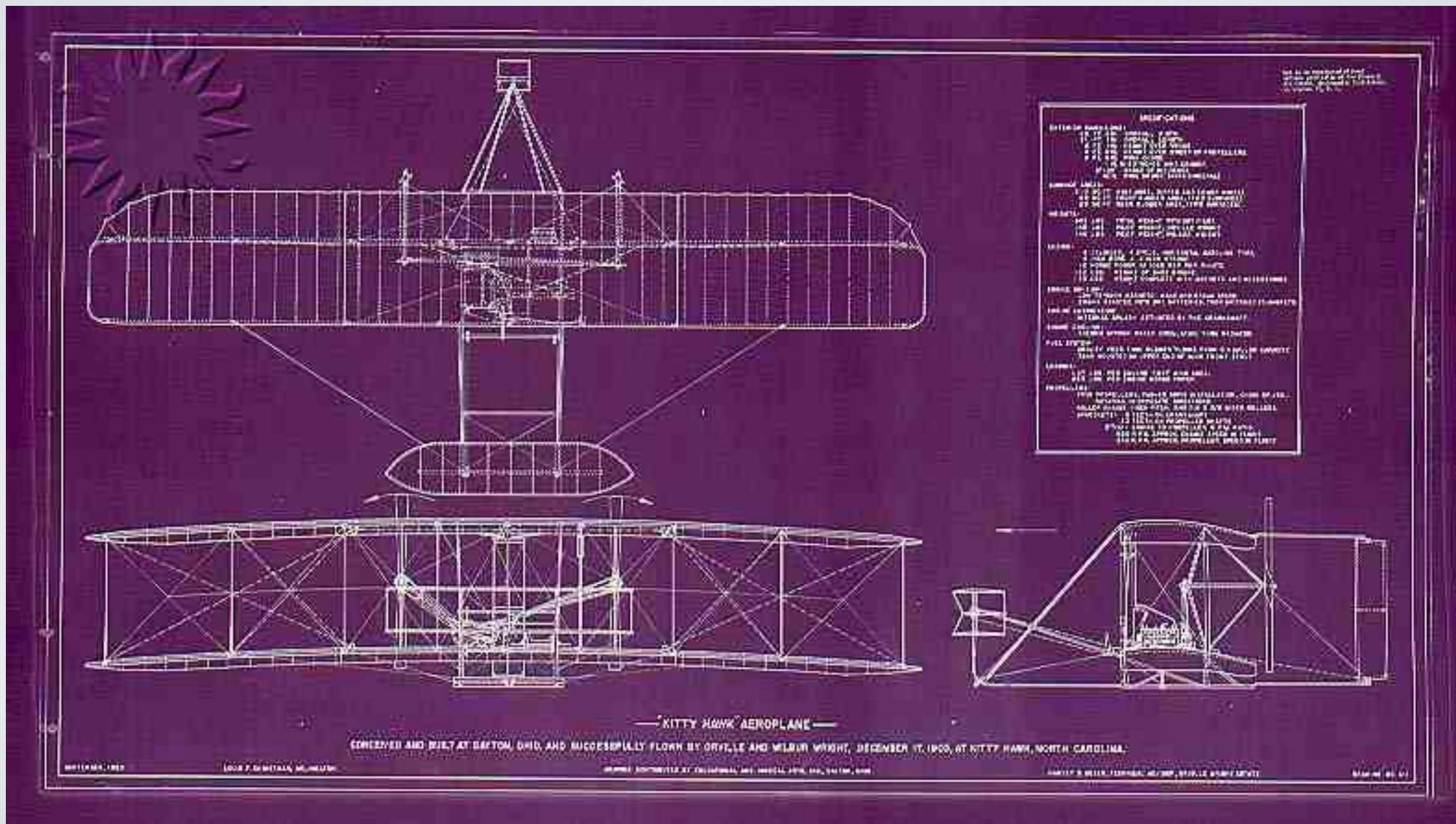
- And with geodesic domes

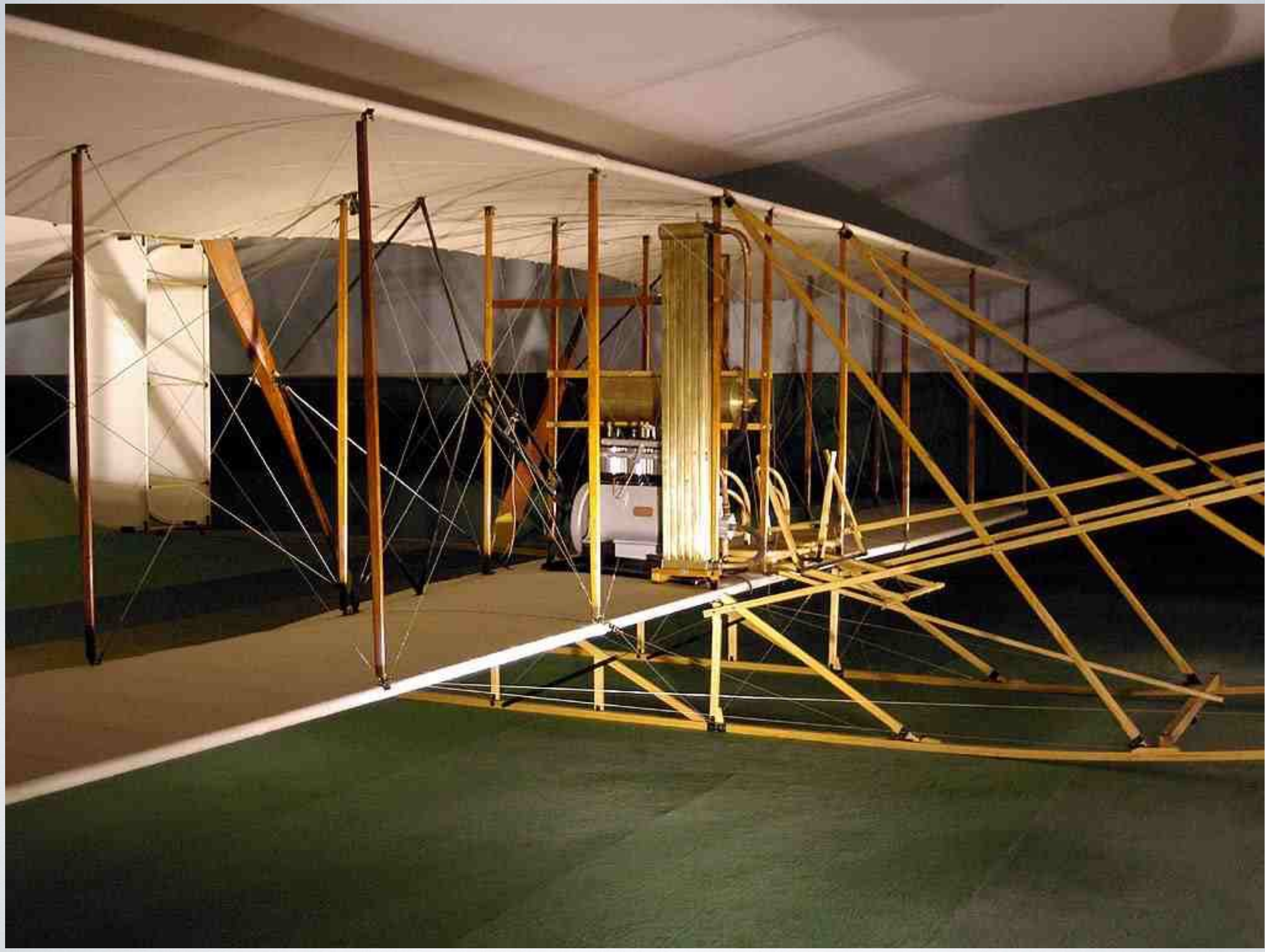


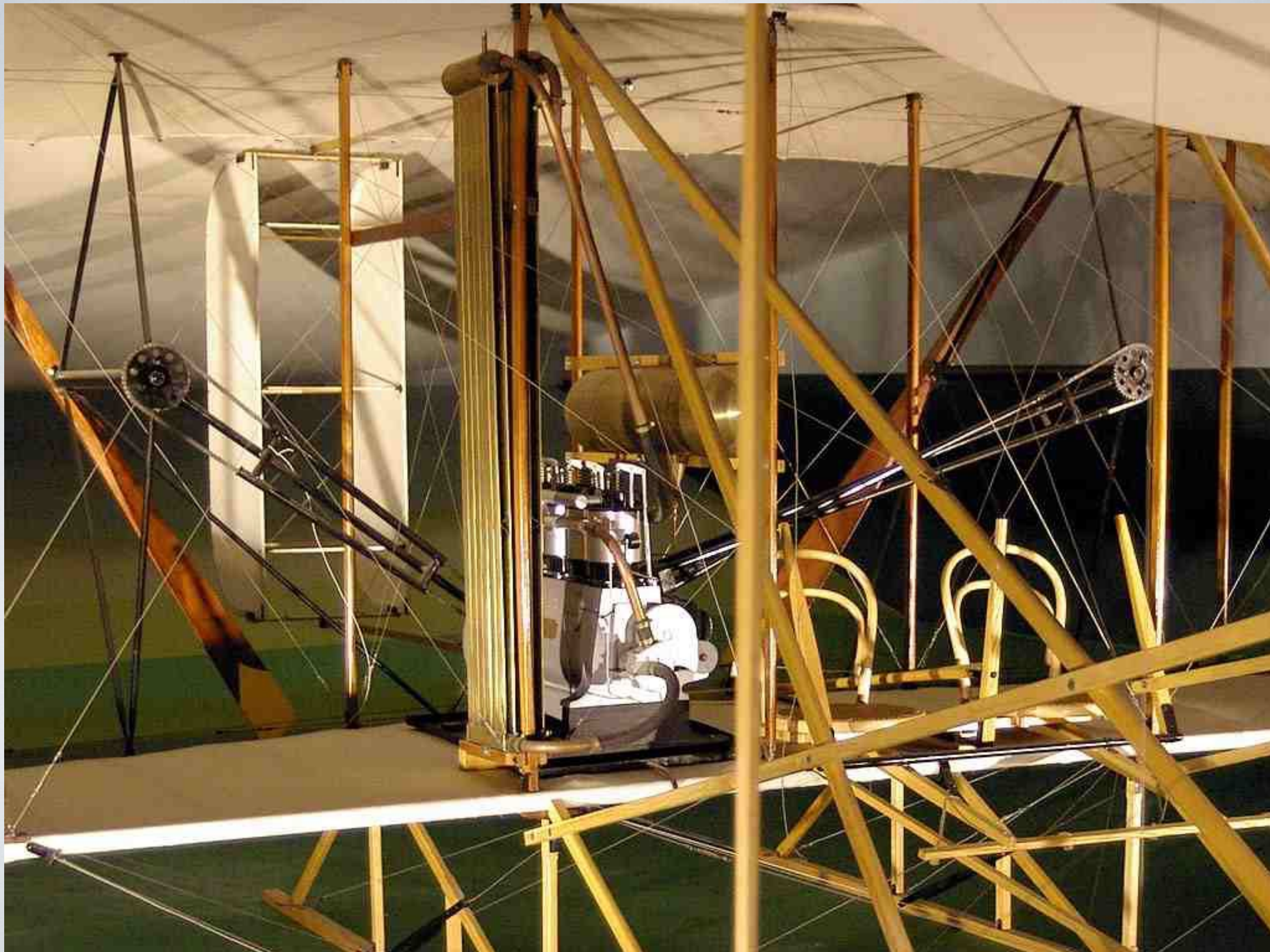
TENSEGRITY

- A little known, yet decidedly famous tensegrity structure is the flying machine that two brothers from Ohio – two bicycle mechanic brothers – designed and built.
- Although many had tried and failed to get off the ground, the Wright's succeeded – and air travel was born.

TENSEGRITY





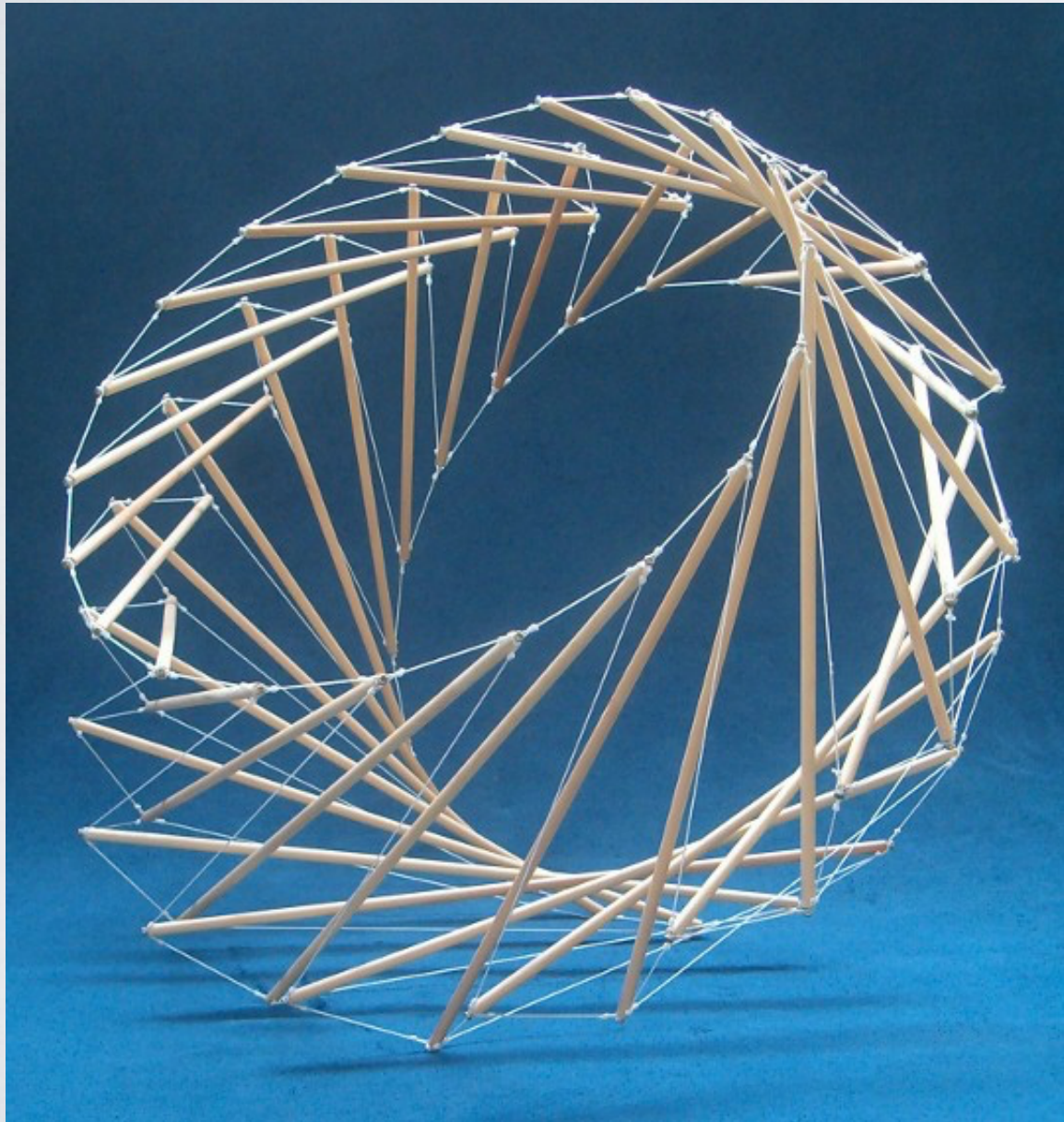




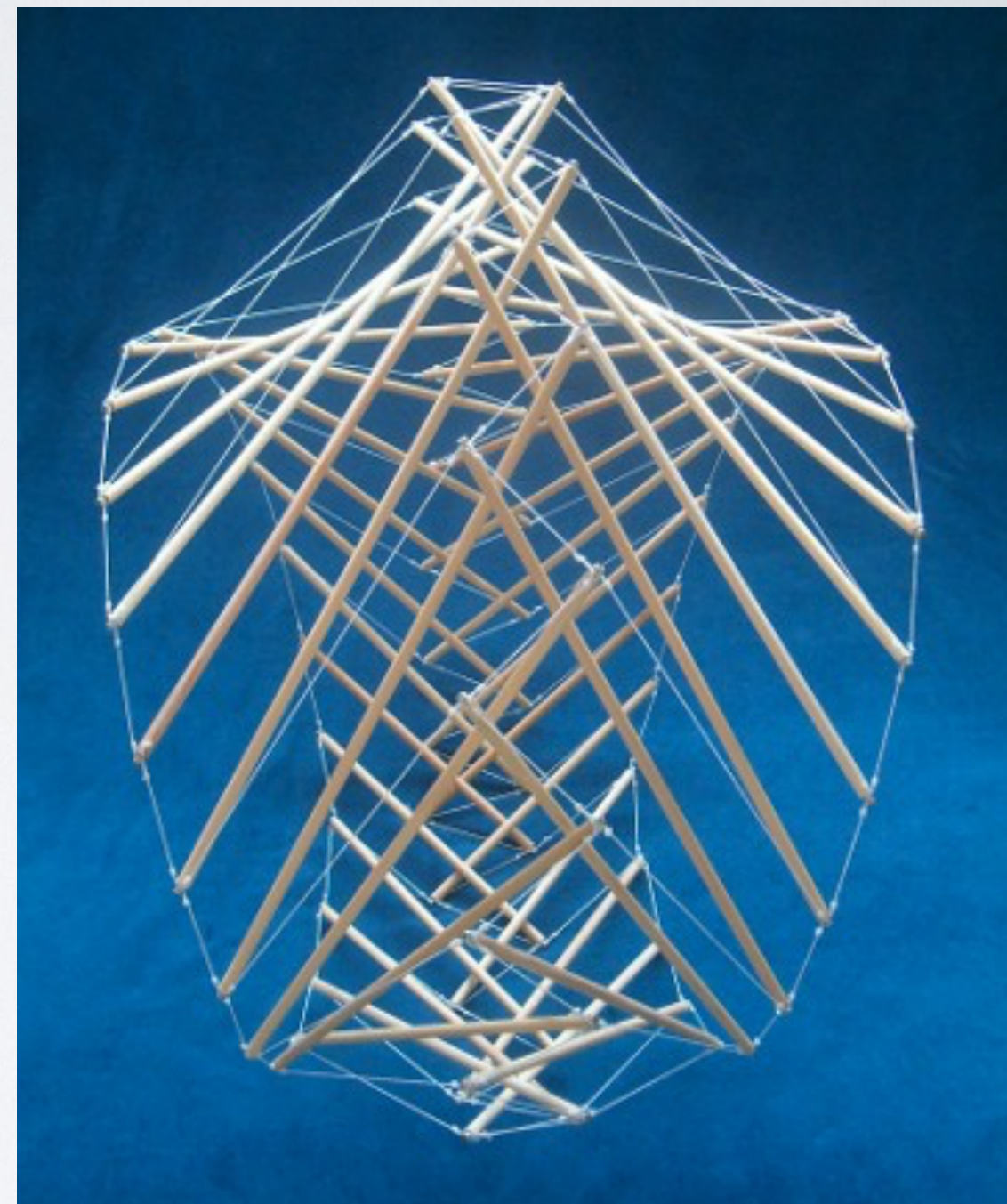
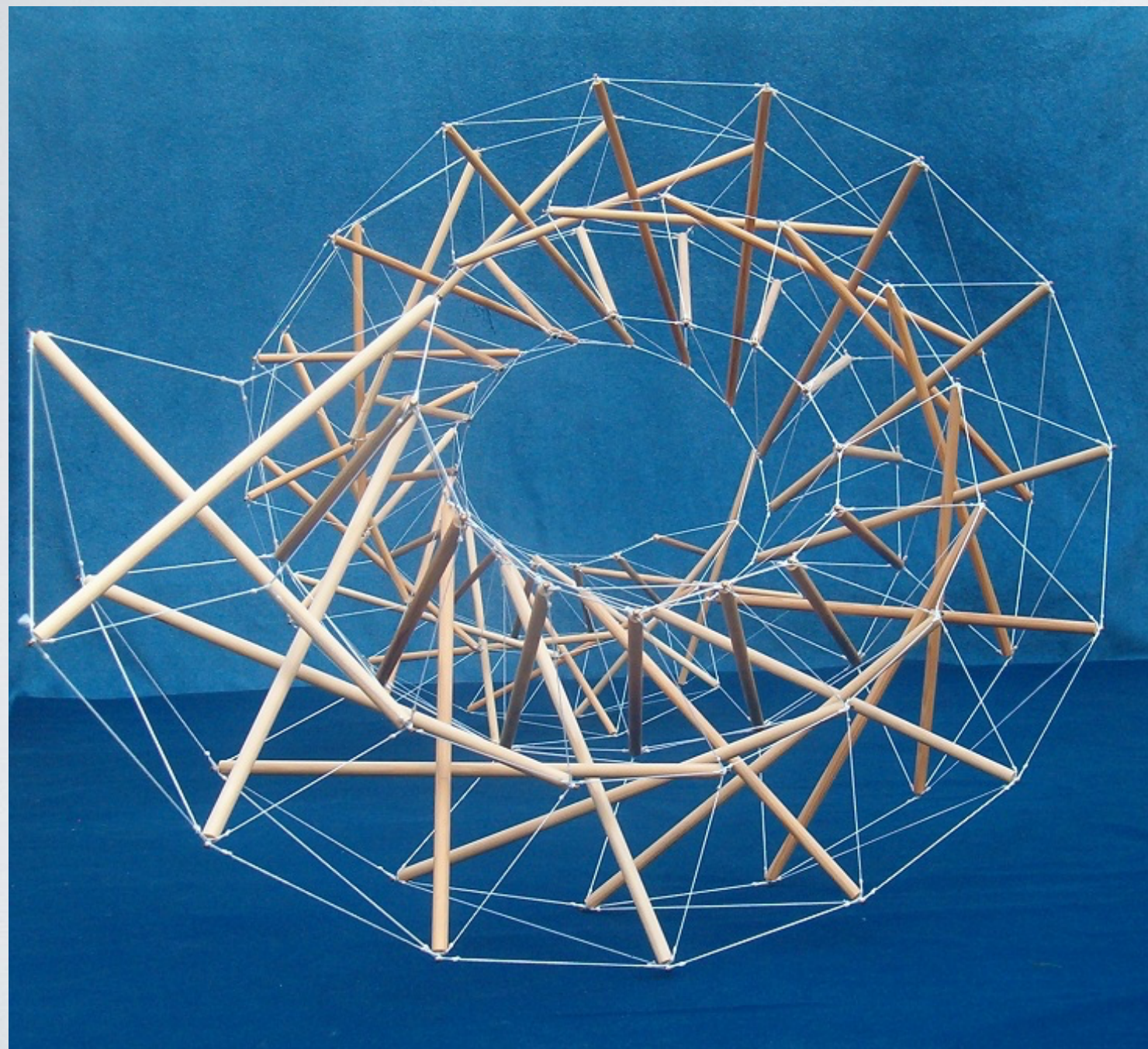
NOTICE THE STEERING DEVICE...A TENSEGRITY
STRUCTURE!

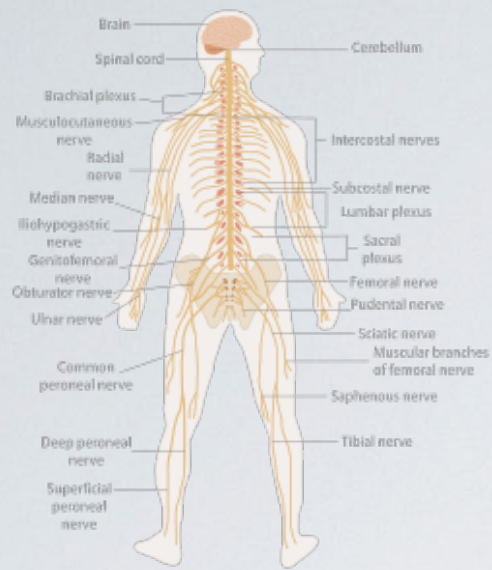


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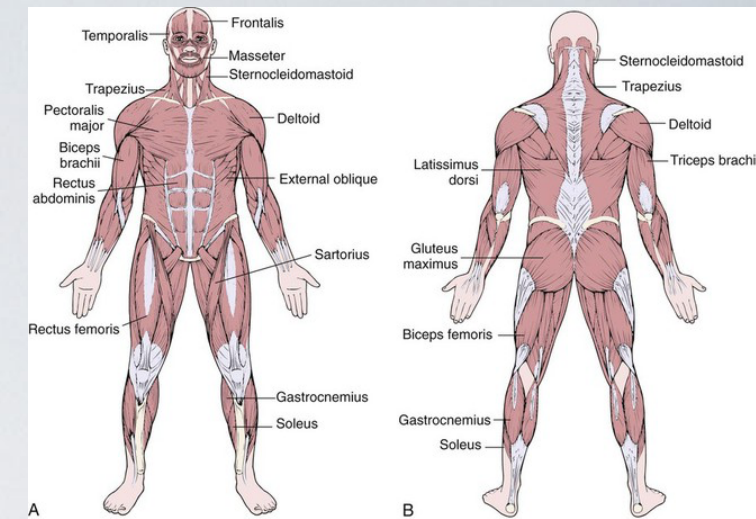


TENSEGRITY





TENSEGRITY



- Here are some other examples of tensegrity in everyday life:
 - In the body -
 - The musculoskeletal system – the muscles continuously pull while the bones discontinuously push. The ligaments suspend the bones and muscles provide the lift against gravity.
 - The central nervous system – sensory neurons are continuously pulling in information (to the tune of over 2000 bits per second) while the motor neurons are occasionally activated – discontinuous push.

TENSEGRITY



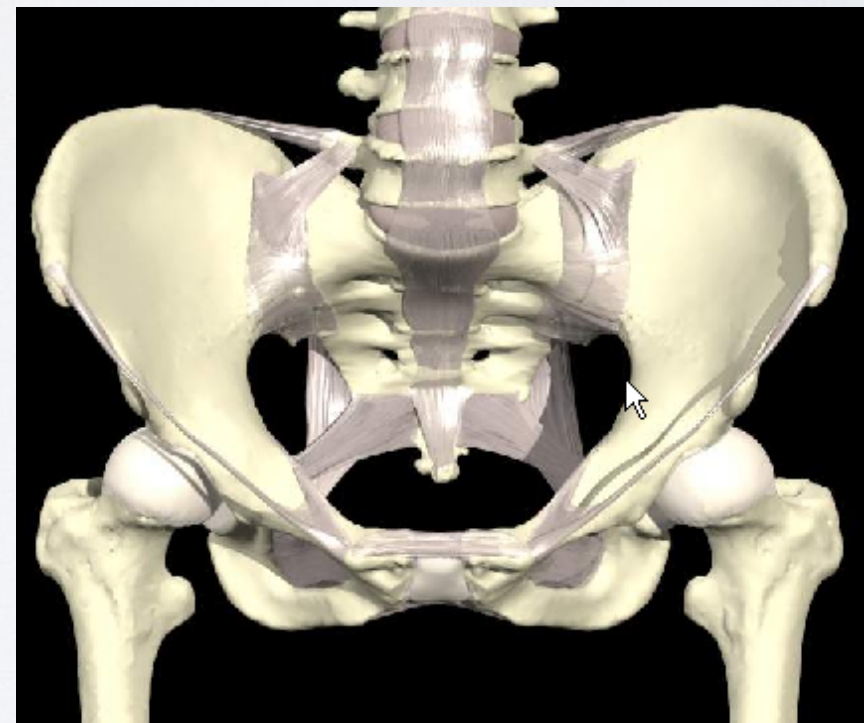
- In the environment -
 - The sun – plants continuously pull light toward their leaves, but due to the weather patterns the sun only discontinuously pushes its light to them.
 - Humans as students and teachers. We are continuously pulling in information and learning as students. I discontinuously push information out to others as a teacher.
 - Humans can form synergistic tensegrities when we are continuously being helped and discontinuously helping others.

TENSEGRITY

Let's take this new knowledge and return to the body.

TENSEGRITY

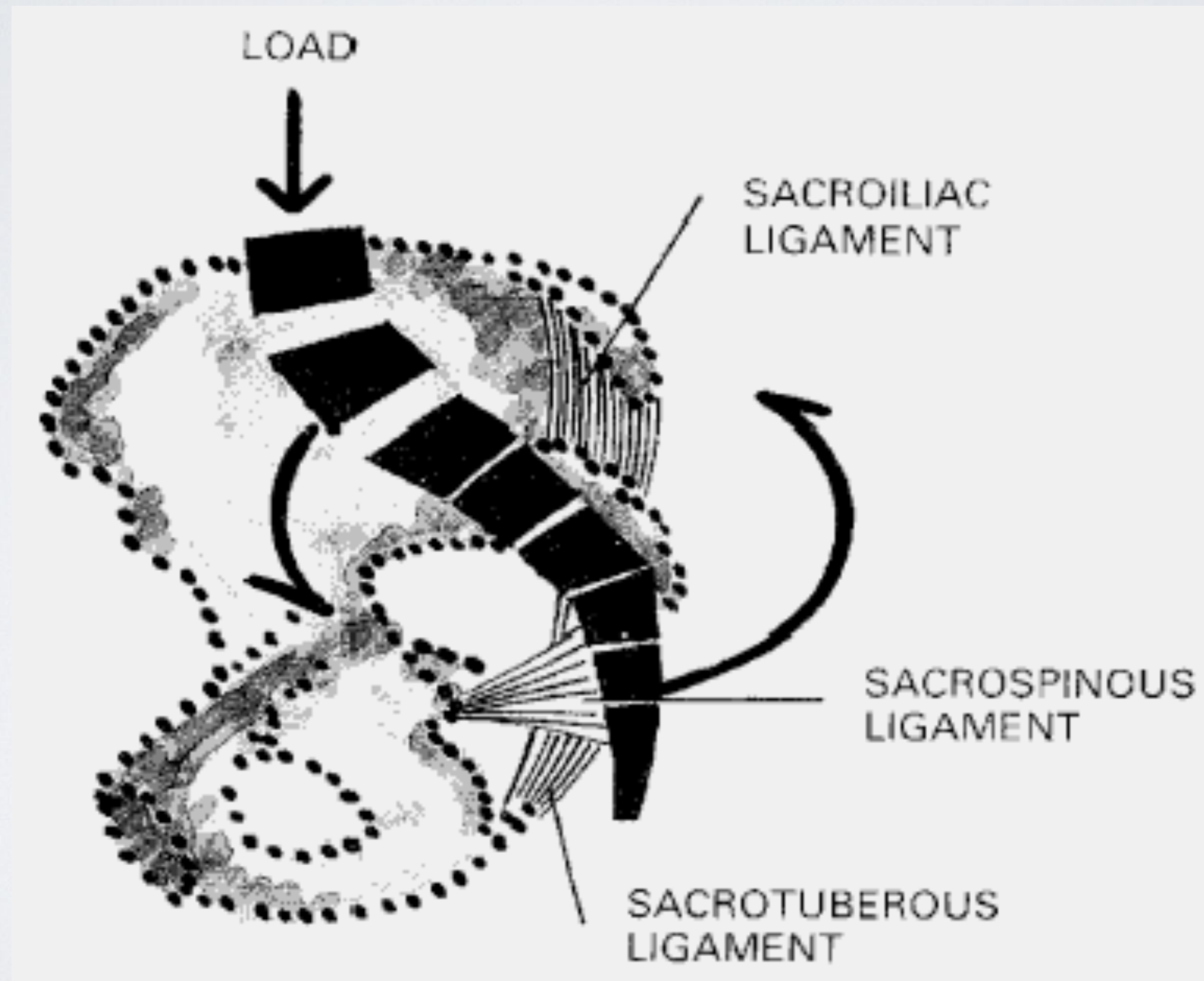
- If we can accept as fact that the sacrum hangs from the ilia by its ligaments.



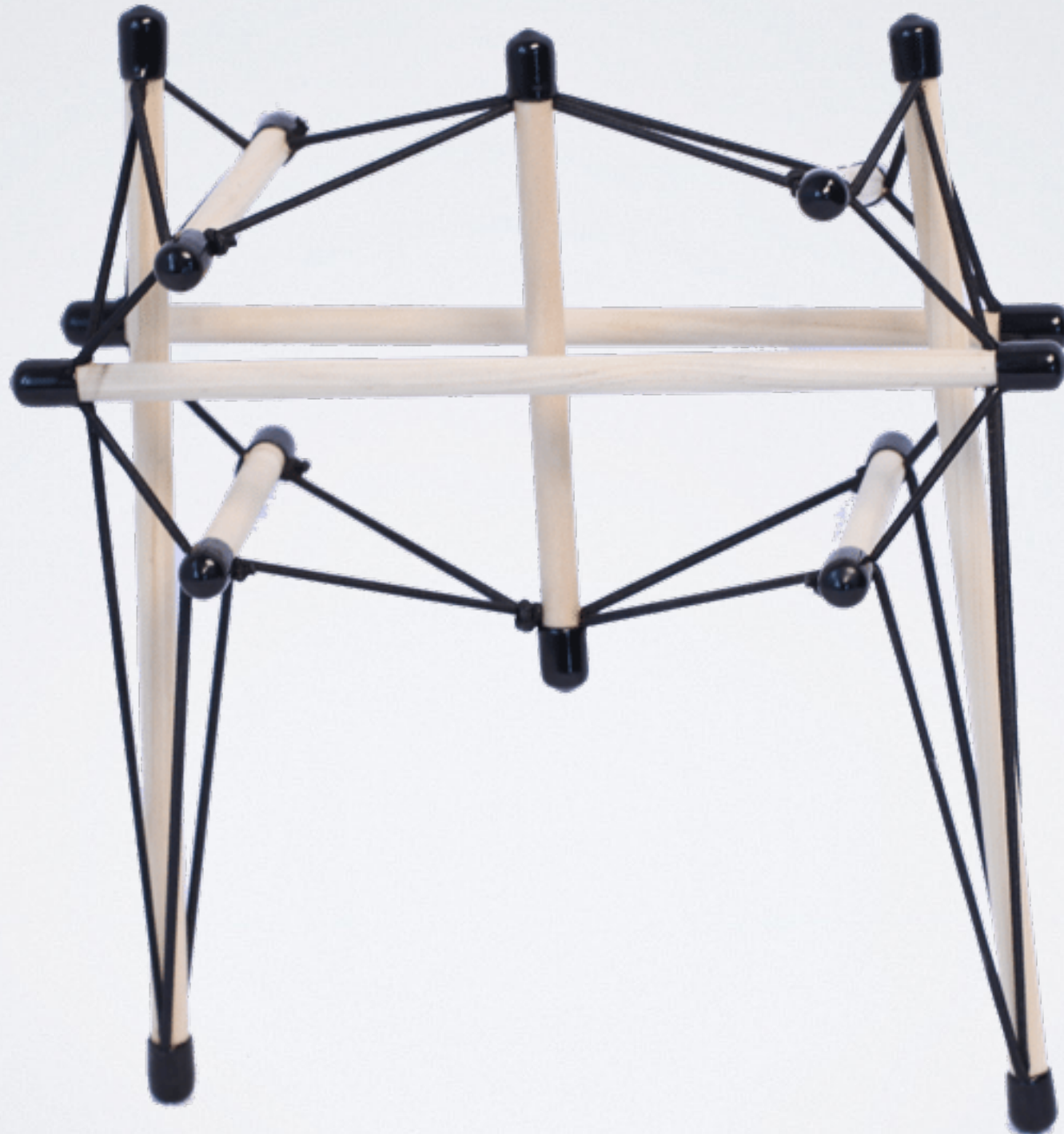
TENSEGRITY

- We can then compare the pelvis with a bicycle wheel.
 - The pelvic ring would be the rim.
 - The sacrum would be the hub.
 - The multitude of ligaments and muscles that attach to the sacrum stabilize it.
 - There is continuous pull (a stabilizing force) from the ligaments to balance the discontinuous push of postural movements.
 - This model allows omnidirectional load distribution and structural stability – independent of gravity.

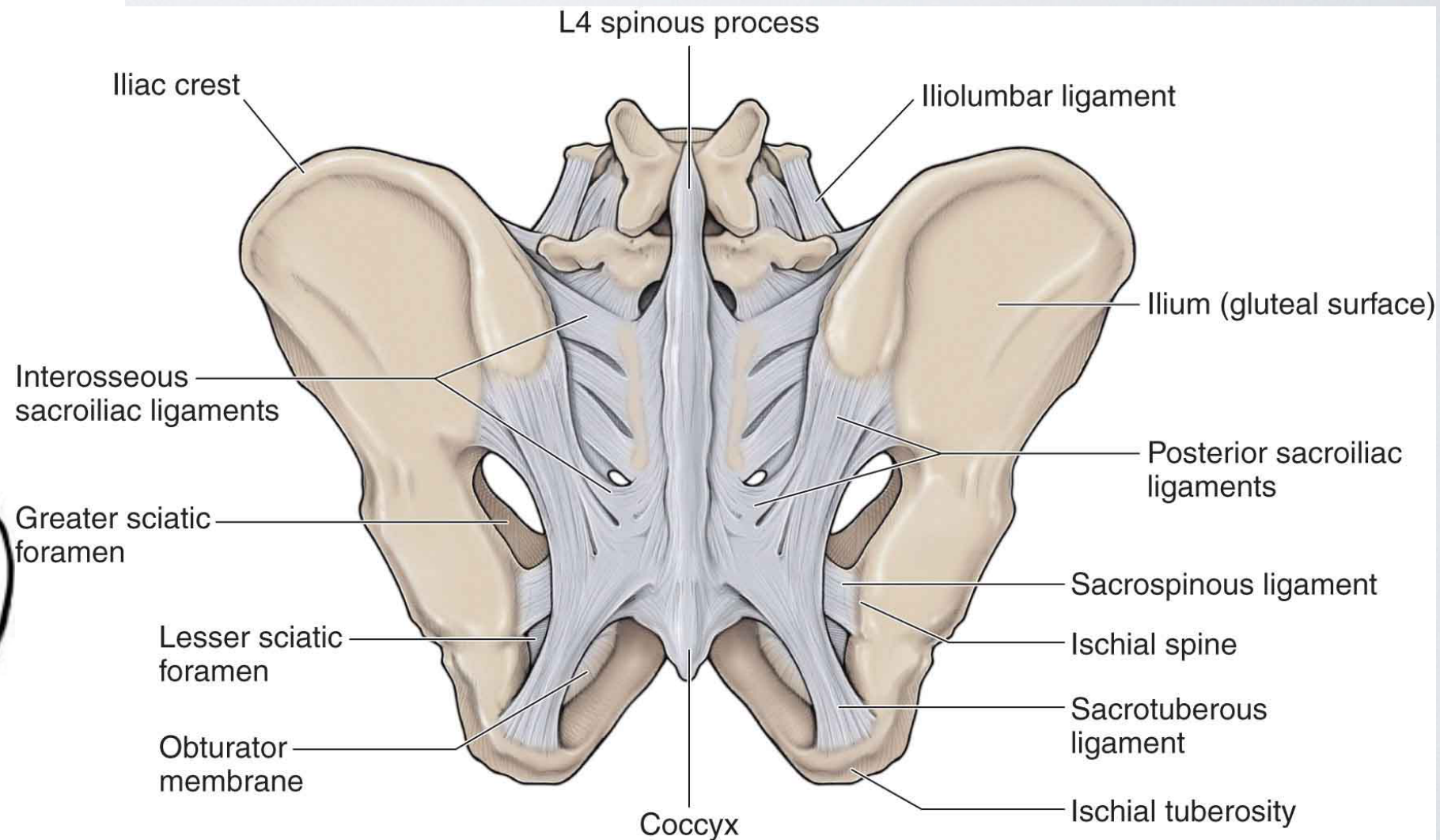
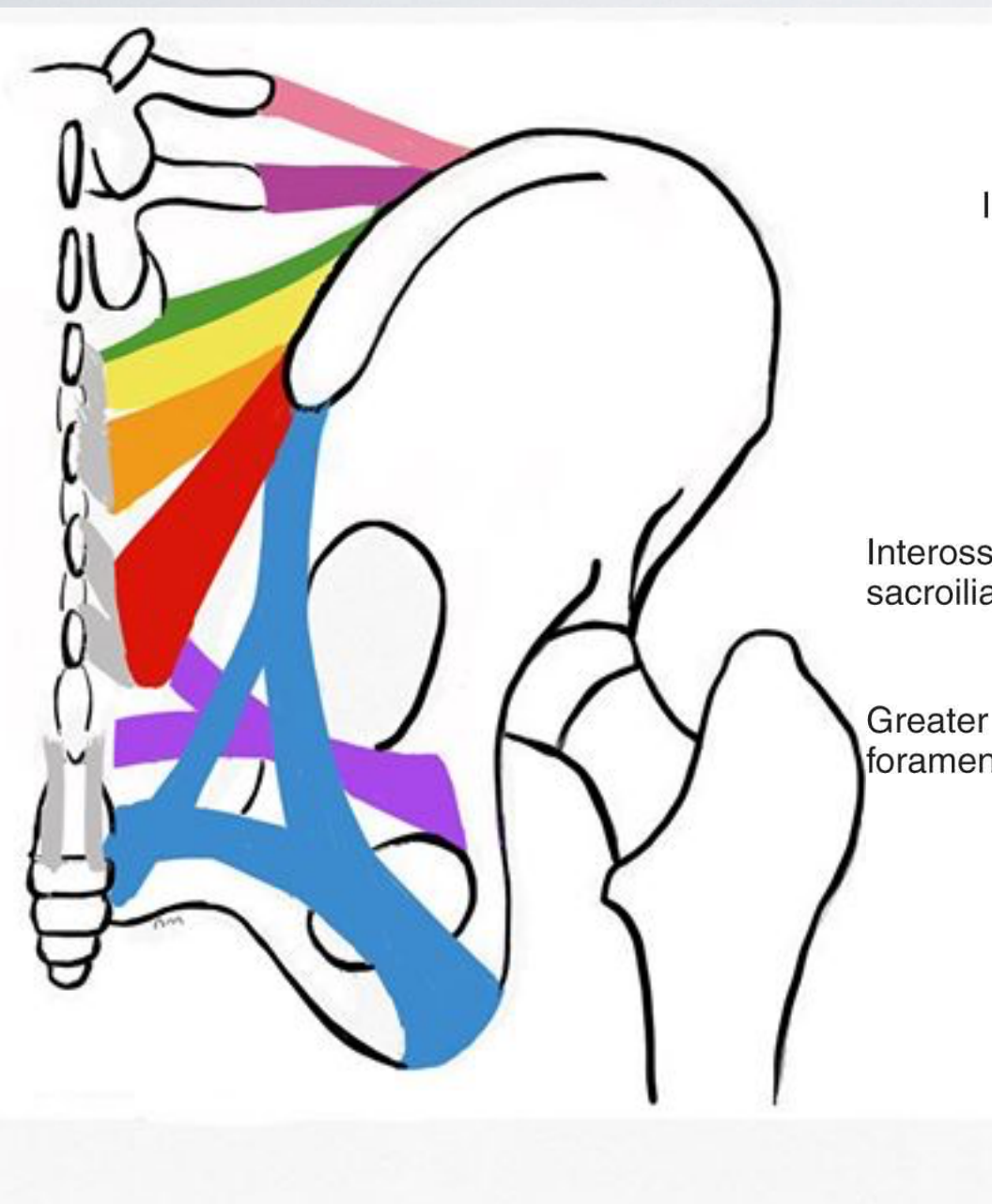
TENSEGRITY



TENSEGRITY



TENSEGRITY



TENSEGRITY

- This tensegrity model of the pelvis will work in and bodily direction:
 - Standing
 - Sitting
 - Upside down
 - Sideways
- It even works in space, in horizontal horses, flying animals like bats, and swimming animals like whales.

Remember, were it not for tensegrity,
this male sperm whale could not exist!



TENSEGRITY

- Remember how it took 12 spokes to make a wheel with a hub that was in a fixed position?
- It is the same in the pelvis. We must have a minimum of 12 attachment points (giving 6 axes) to stabilize that sacrum in space and make it a fixed relation to the innomimates.
- Fred Mitchell, Sr., D.O. demonstrated those axes long before tensegrity as a concept was imagined.

TENSEGRITY

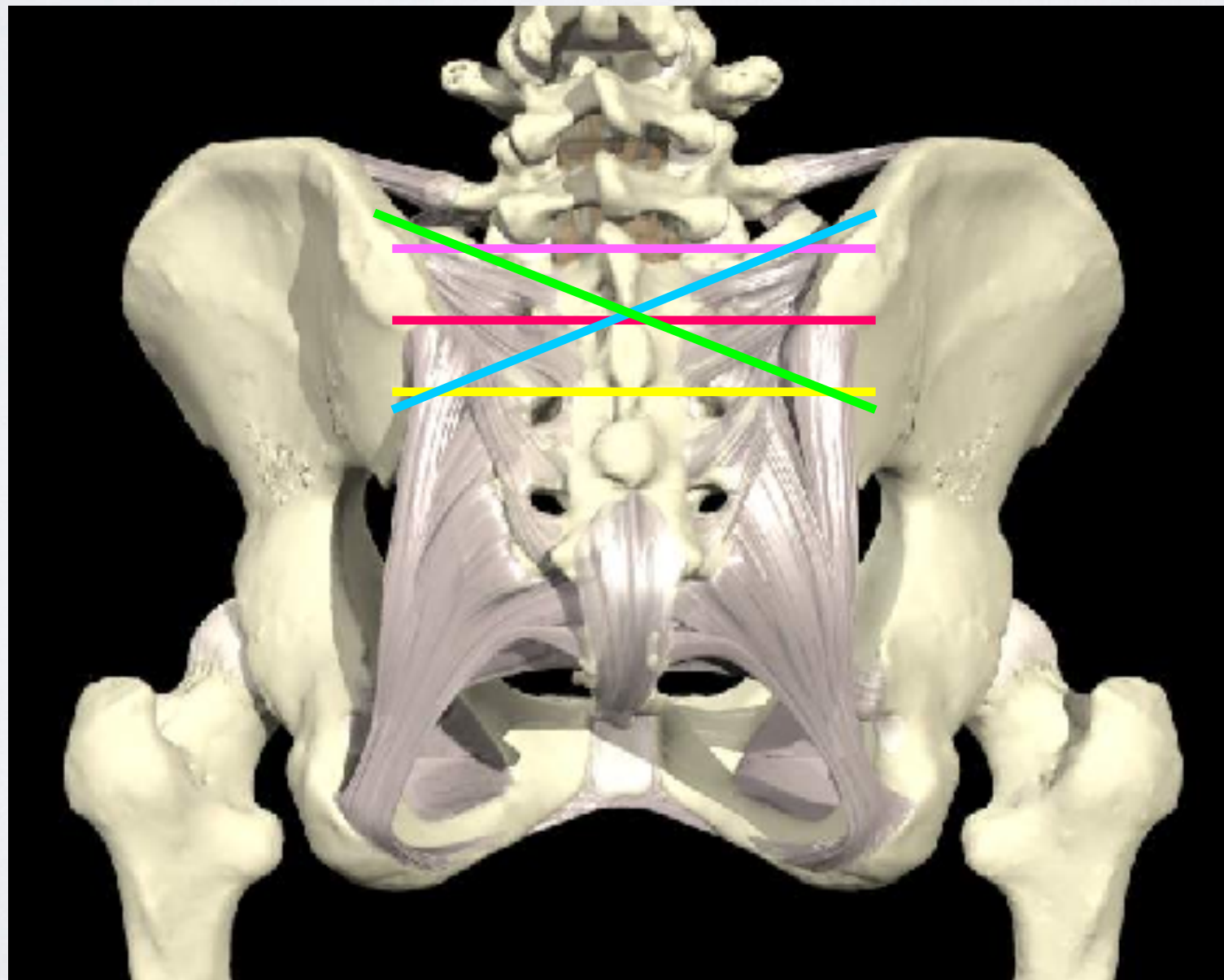
- We are going to cover the Mitchell Model of pelvic motion in much more detail later in the presentation, so if this is a new concept for you please be patient and it should make more sense as we go along.
- The following is a brief introduction to the axes system.

TENSEGRITY

- There are six axes and each has a bodily motion that is easiest around that axis (and thus it is where certain restrictions will be found):
 - Superior Transverse Axis – Cranial Motion
 - Middle Transverse Axis – Sacral Flexions and Extensions.
 - Inferior Transverse Axis – Innominate Rotations.
 - Left Oblique and Right Oblique Axis – Sacral Torsions
 - Anterior / Posterior Axis – Anterior / Posterior Shears

TENSEGRITY

- 1) Superior Transverse Axis
- 2) Middle Transverse Axis
- 3) Inferior Transverse Axis
- 4) Left Oblique Axis
- 5) Right Oblique Axis
- 6) Anterior/Posterior Axis



TENSEGRITY

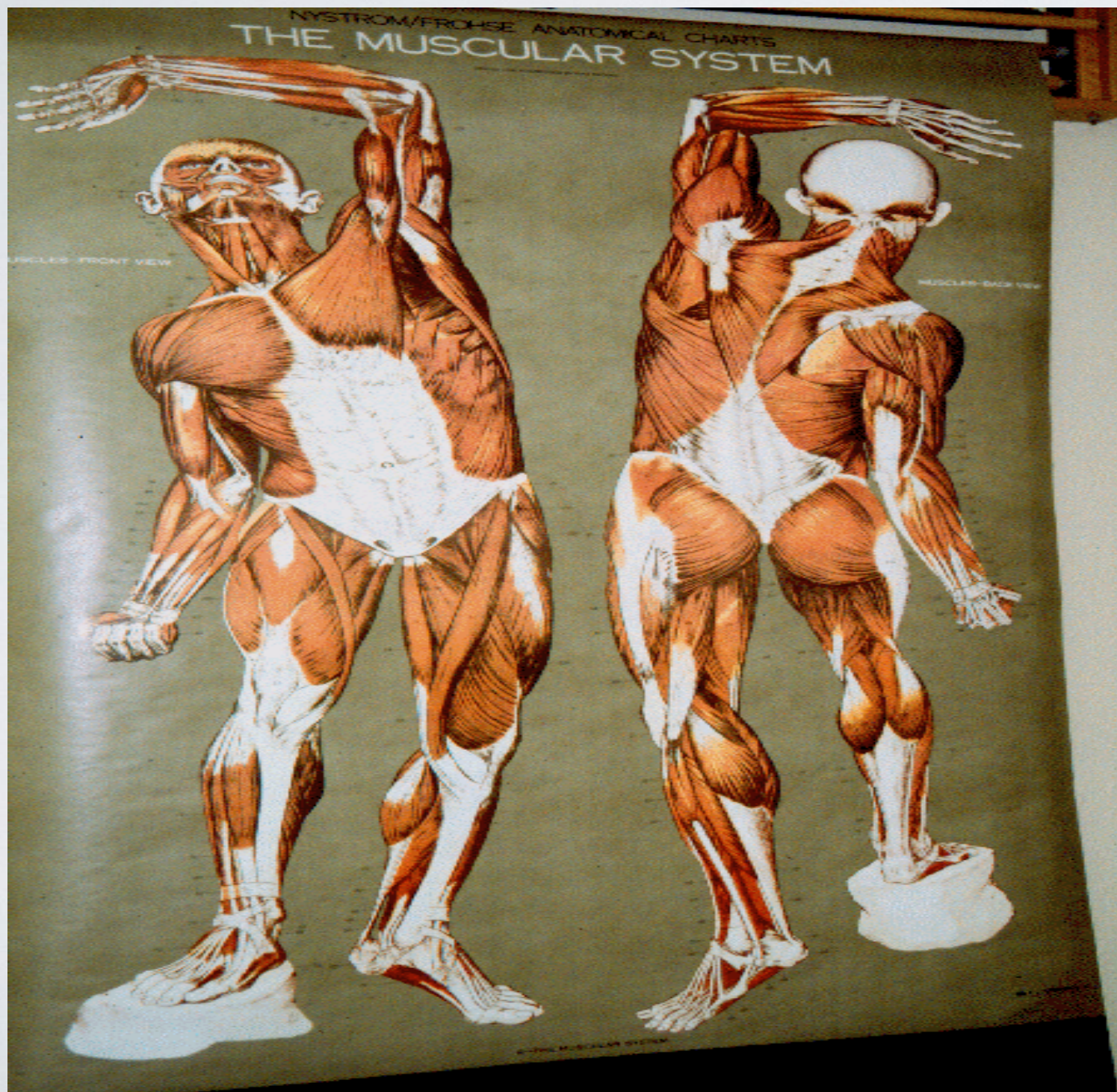
- The three transverse axes would tend to rigidly lock the sacrum within the innominates if the innominates were a rigid bone structure.
- This would not allow us to side bend the sacrum or bend forward without possibly destroying the body.
- But, if the sacrum moves in tandem with the other bones of the pelvis, so that the ligaments remain at the same length, tension-coupled movement patterns occur – and the movements of the Mitchell axis system are possible.

TENSEGRITY

“Tensegrity structures are mechanically stable not because of the strength of the individual members but because of the way the entire structure distributes and balances mechanical stress.”

-Ingber

TENSEGRITY



Notice the fascial and ligamentous attachments in the body.

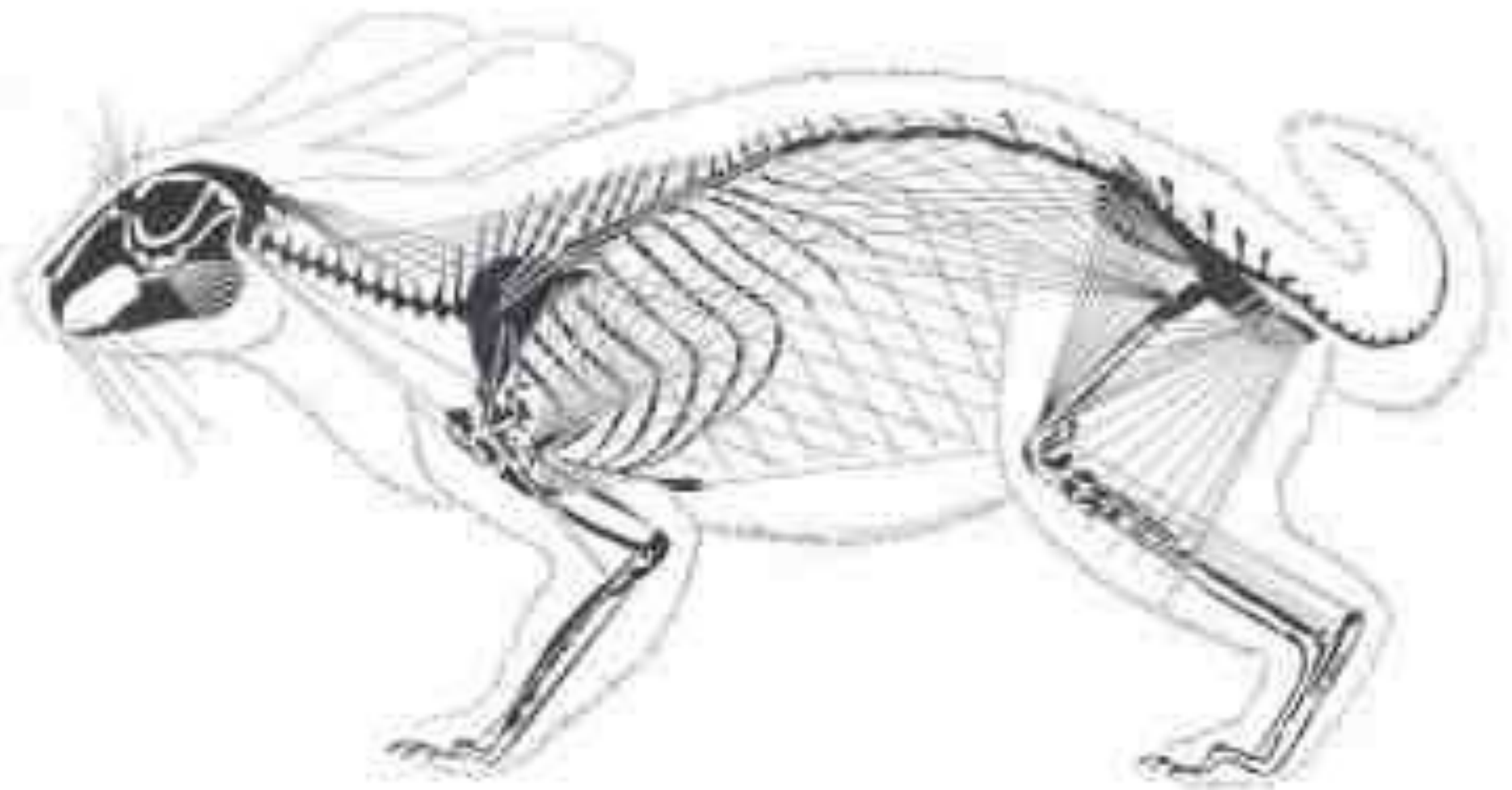
TENSEGRITY

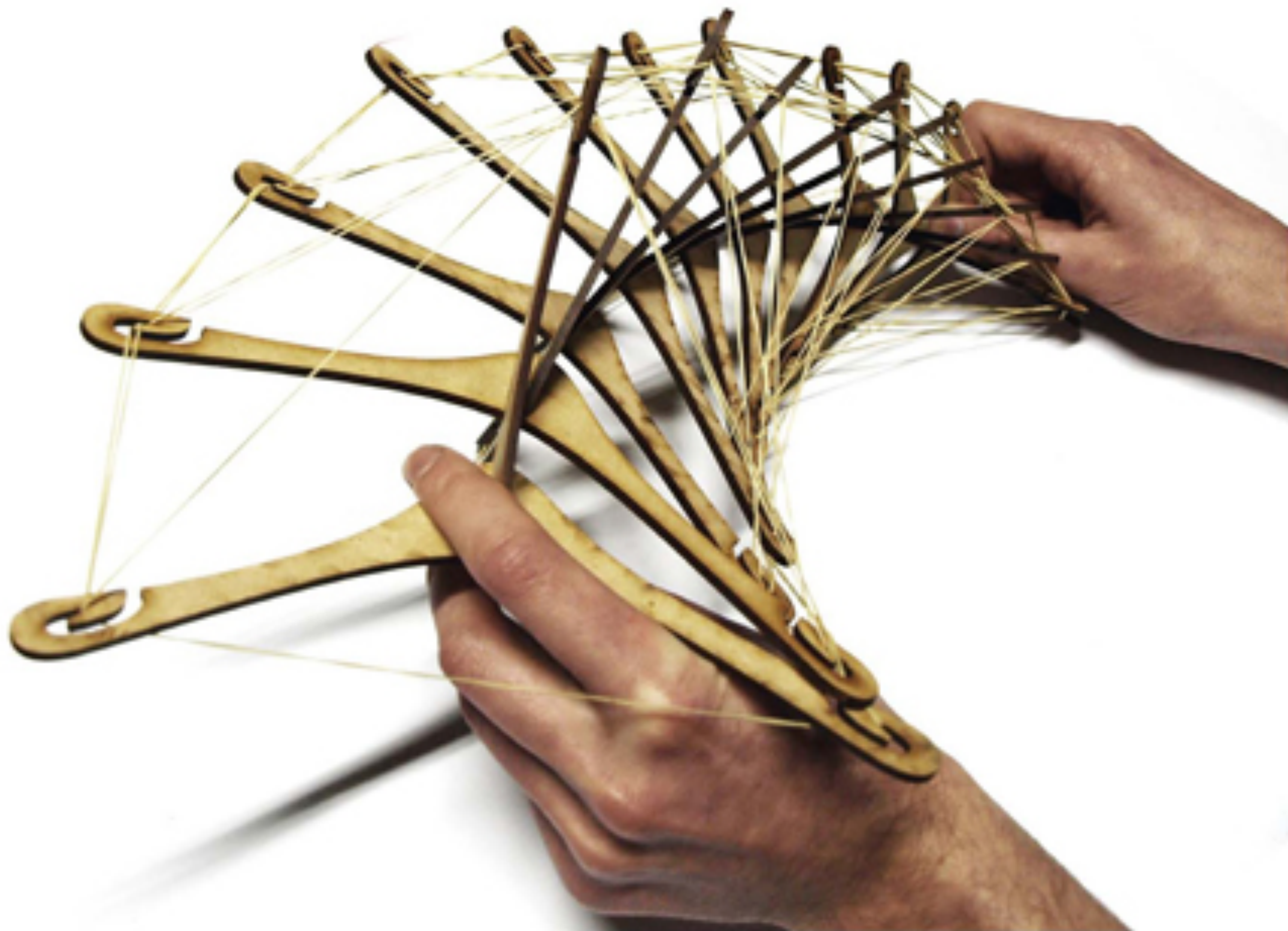
- Is it possible that the entire body is a tensegrity system, or a system of individual tensegrity structures within a more global tensegrity “body”?
- *The larger a tensegrity system is the more stable it becomes.*
- And the more it takes to destabilize it.

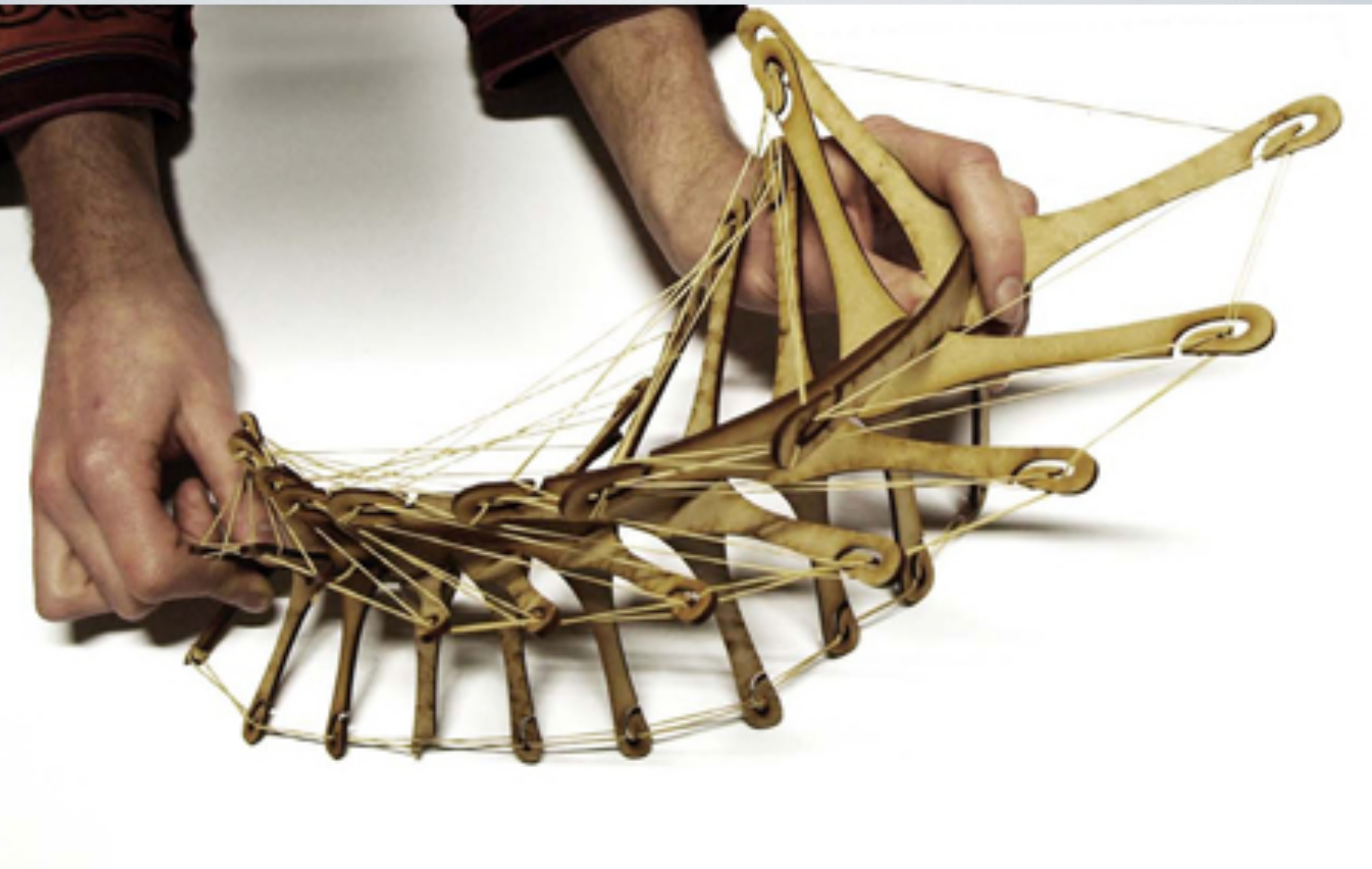
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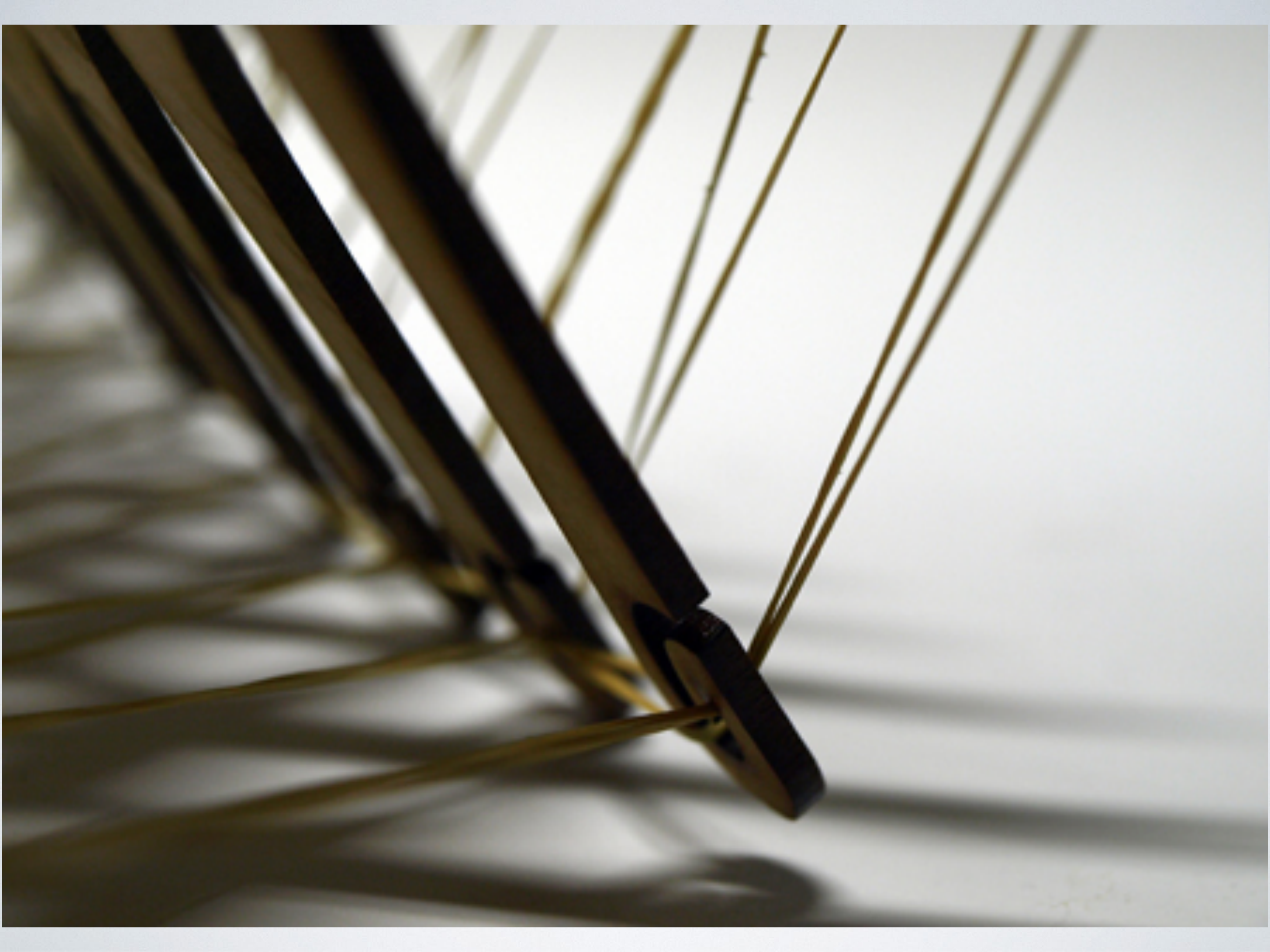


TENSEGRITY





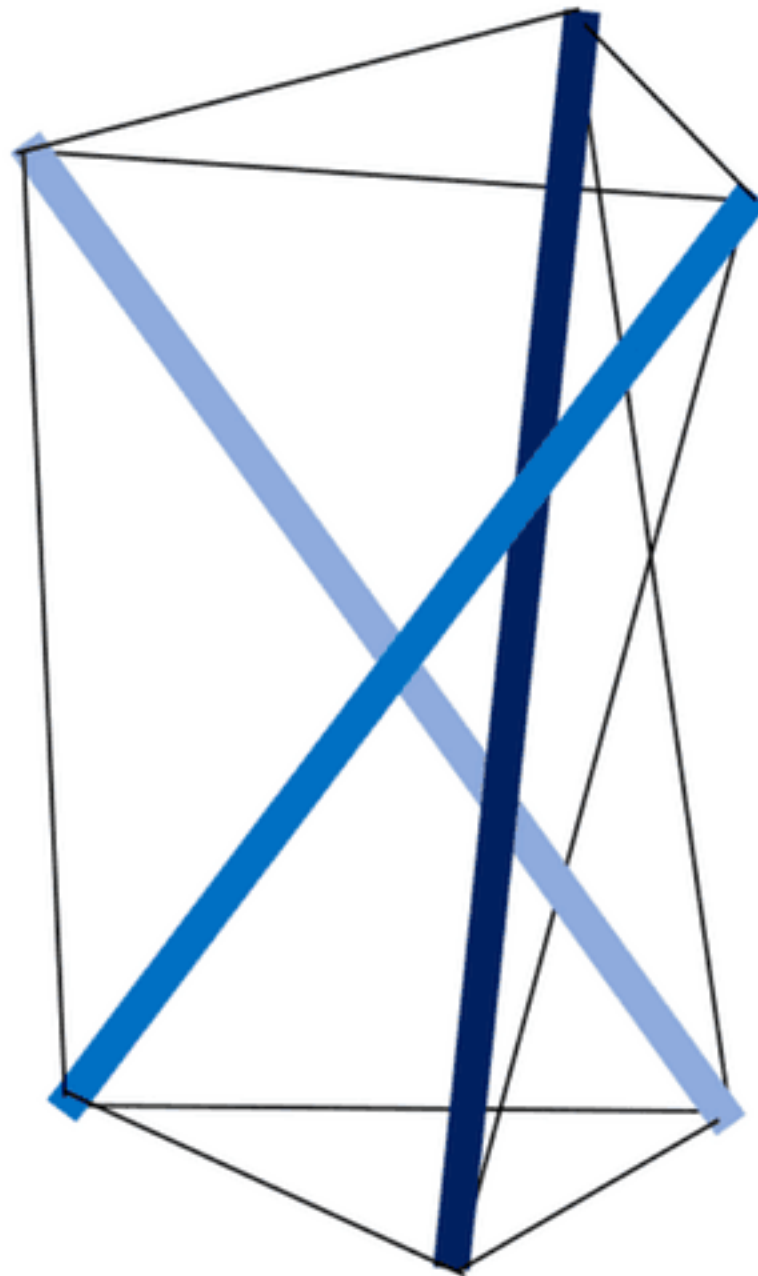




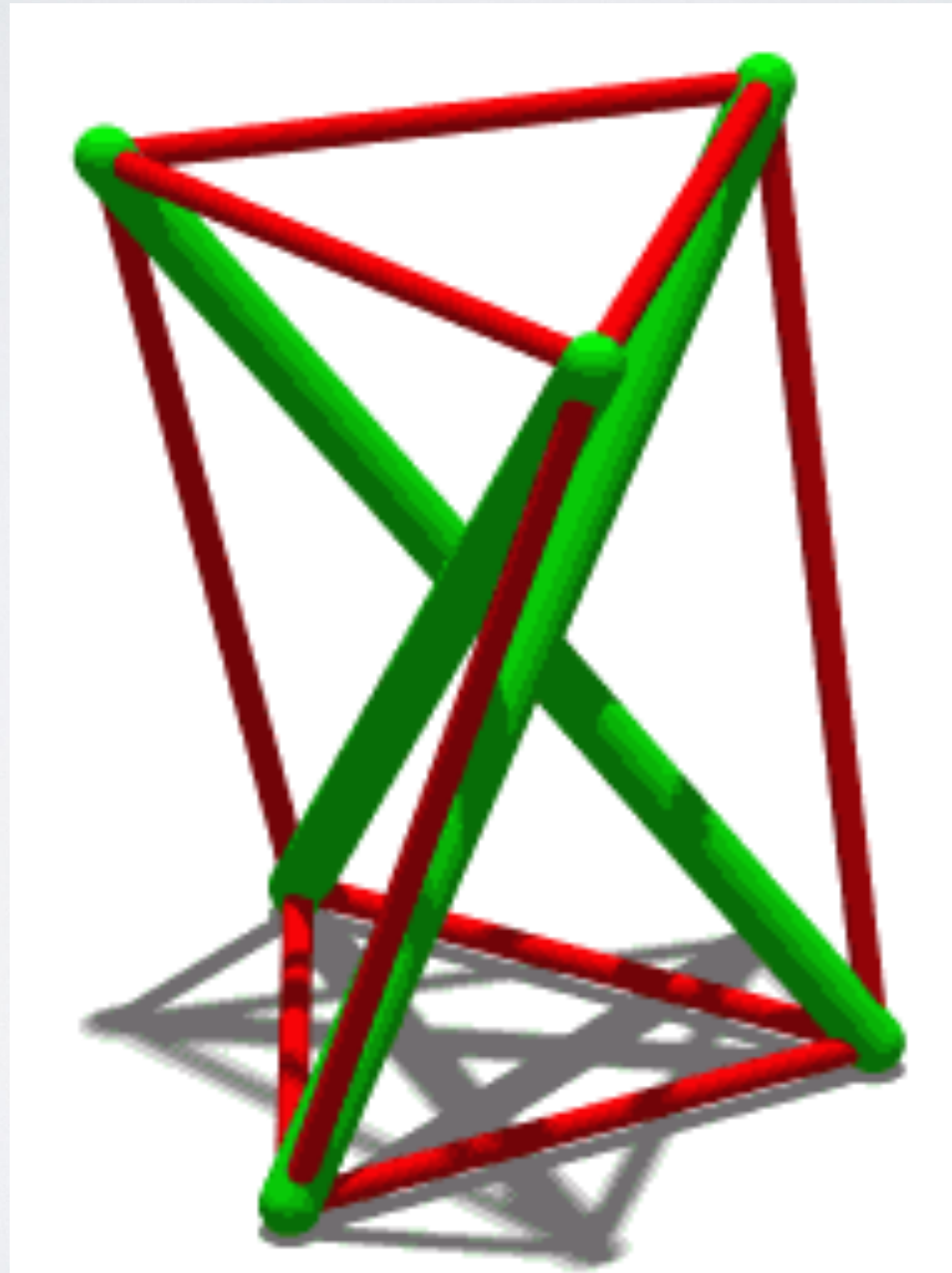


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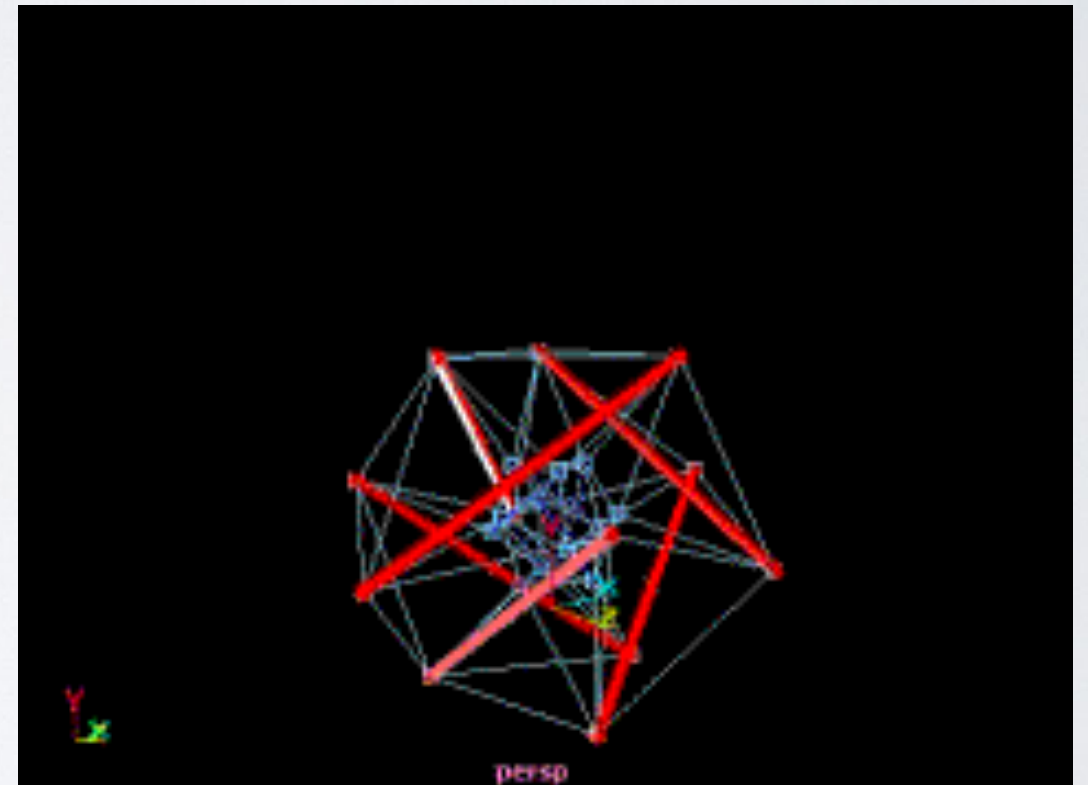
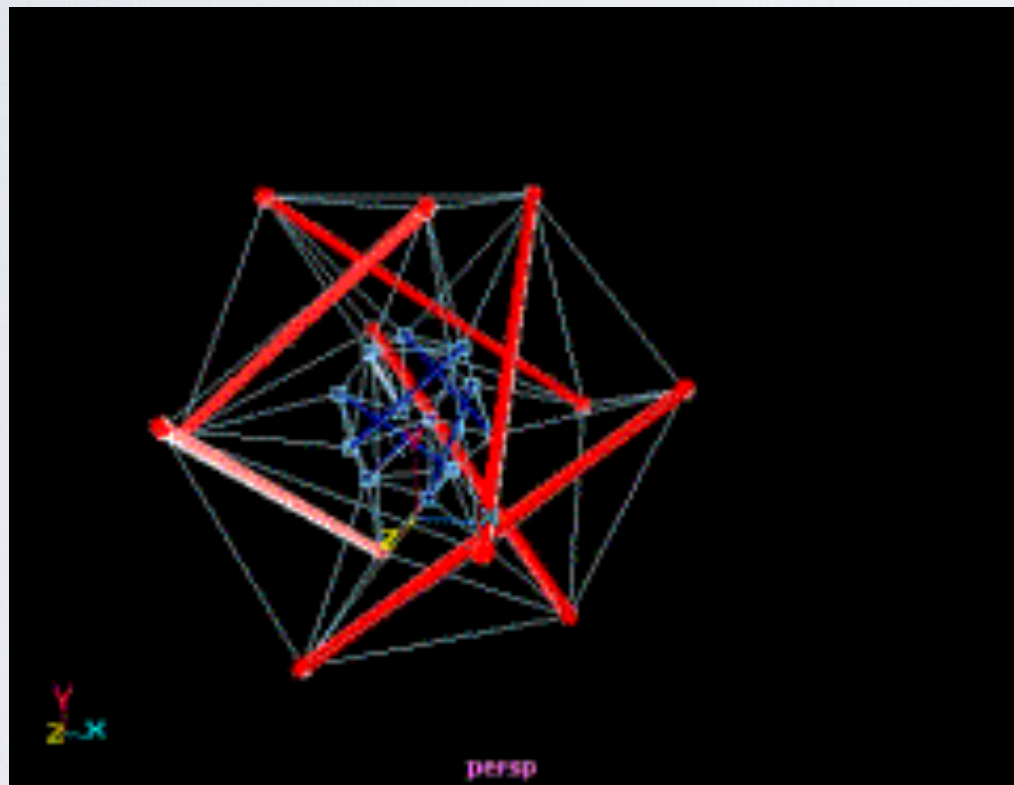
3-Strut Tensegrity Structure

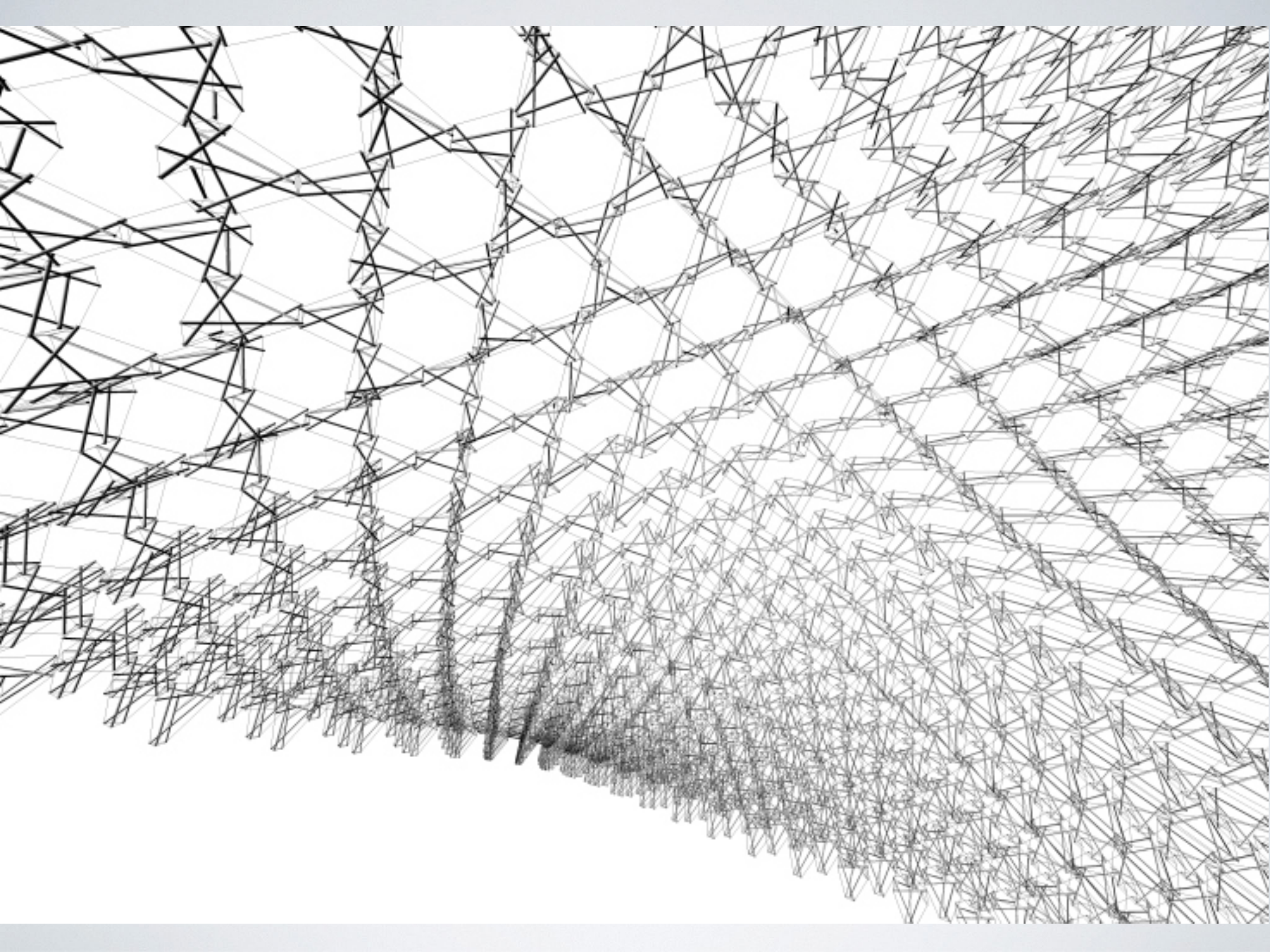


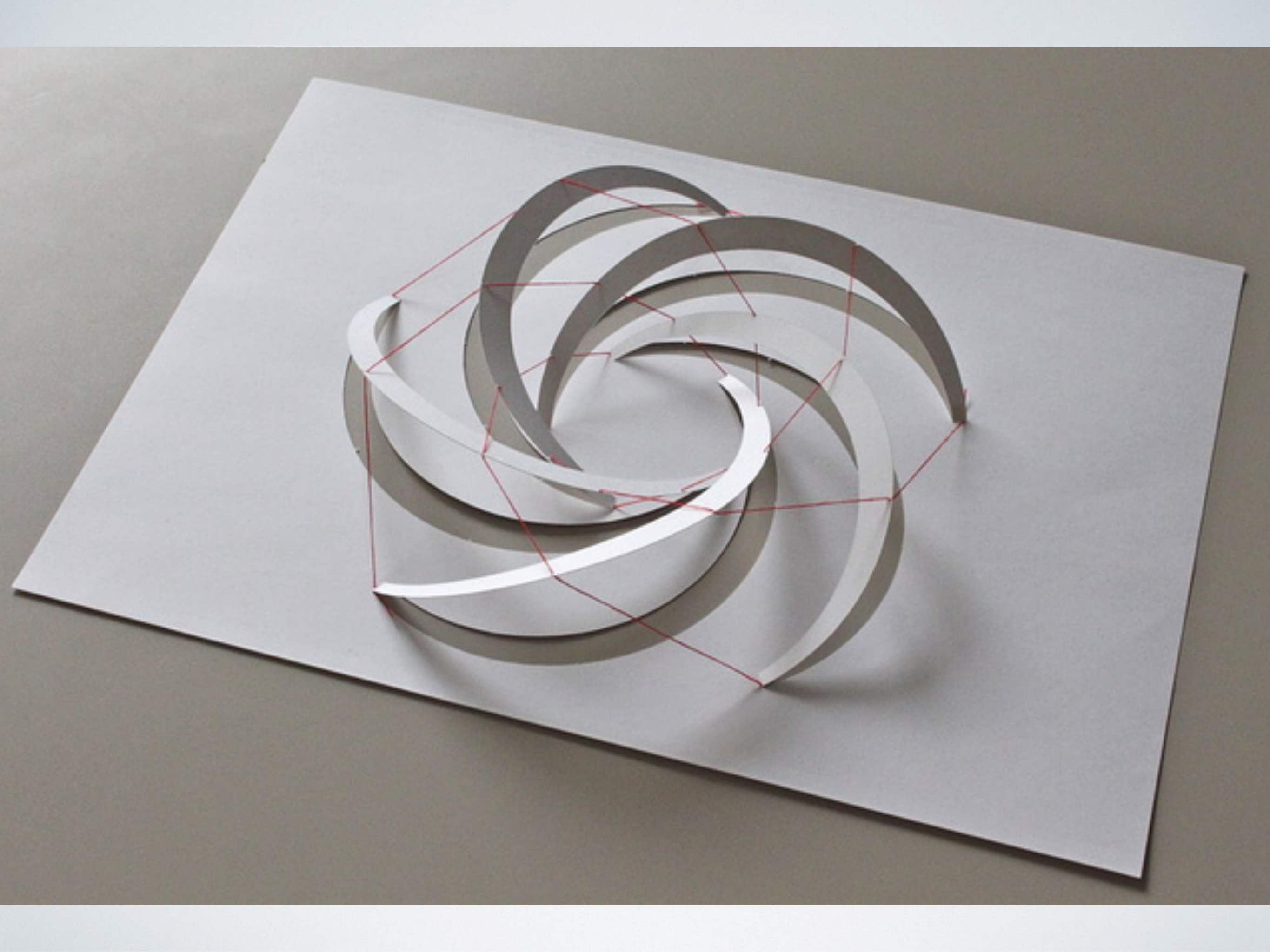
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TENSEGRITY



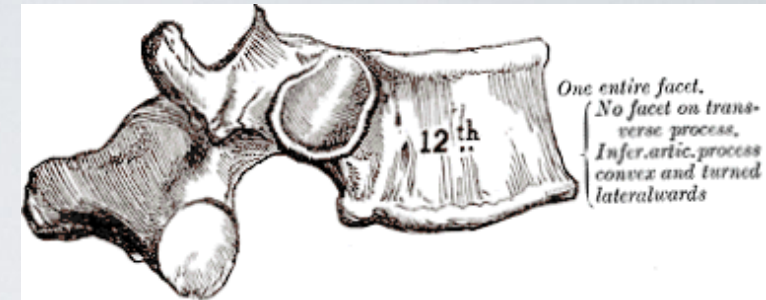




TENSEGRITY

- Let's look at some more parts of the body and explore how they may act as tensegrity systems:
 - T_{12}
 - L_5
 - C_1
 - C_2
 - Ribs 1, 2, 11, 12

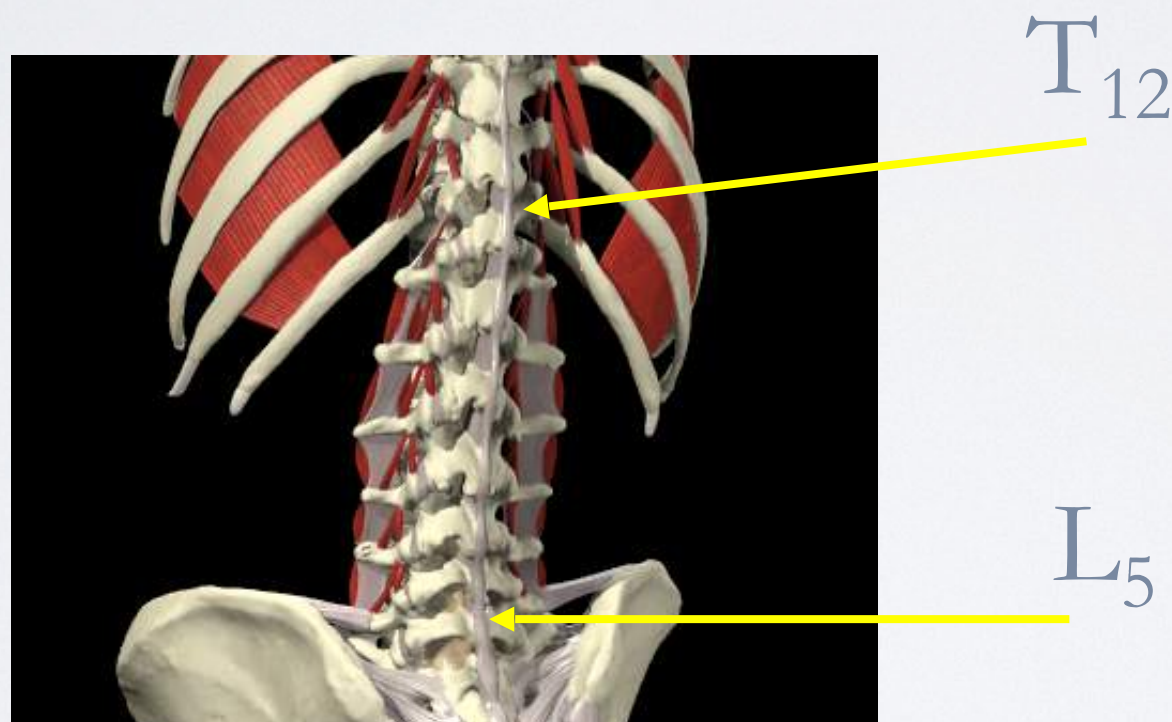
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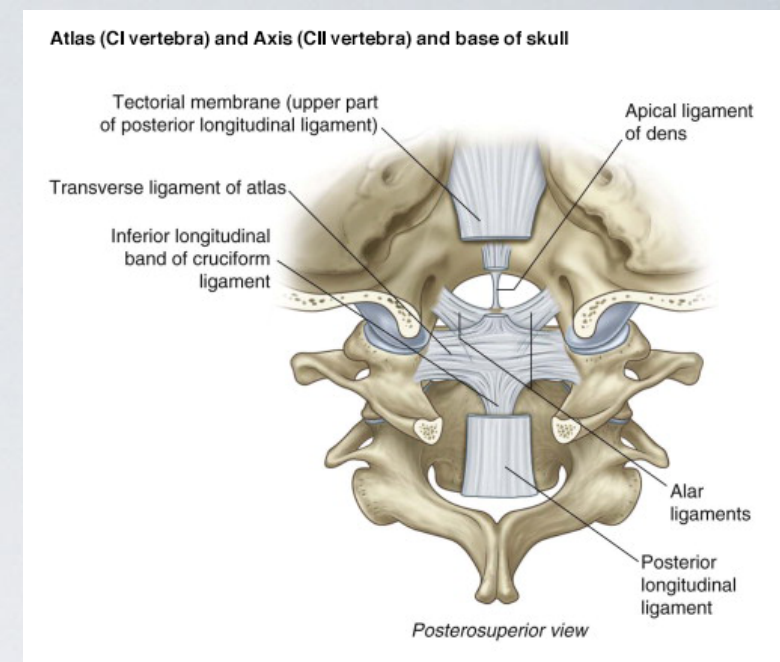
- T_{12} is a unique vertebra in the body. Its upper facet pairs are shaped like that of a thoracic vertebra and its lower ones like that of a lumbar vertebra.
- If for a moment we assume that the rib cage is a *relatively* rigid structure due to the rib heads spanning each vertebral joint *and* that the lumbar spine *relatively* functions as a single unit, then T_{12} becomes a universal joint between the two, allowing many different types of motion.

TENSEGRITY

- L_5 serves much the same function of T_{12} by bridging the gap between the lumbar spine and the *relatively* rigid sacrum.

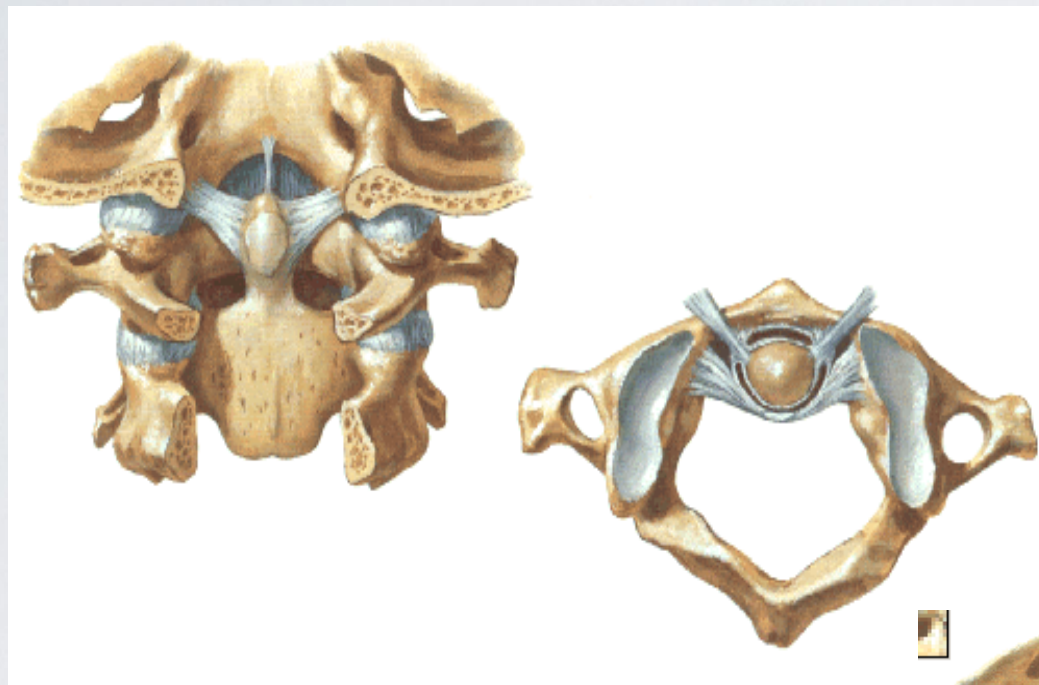


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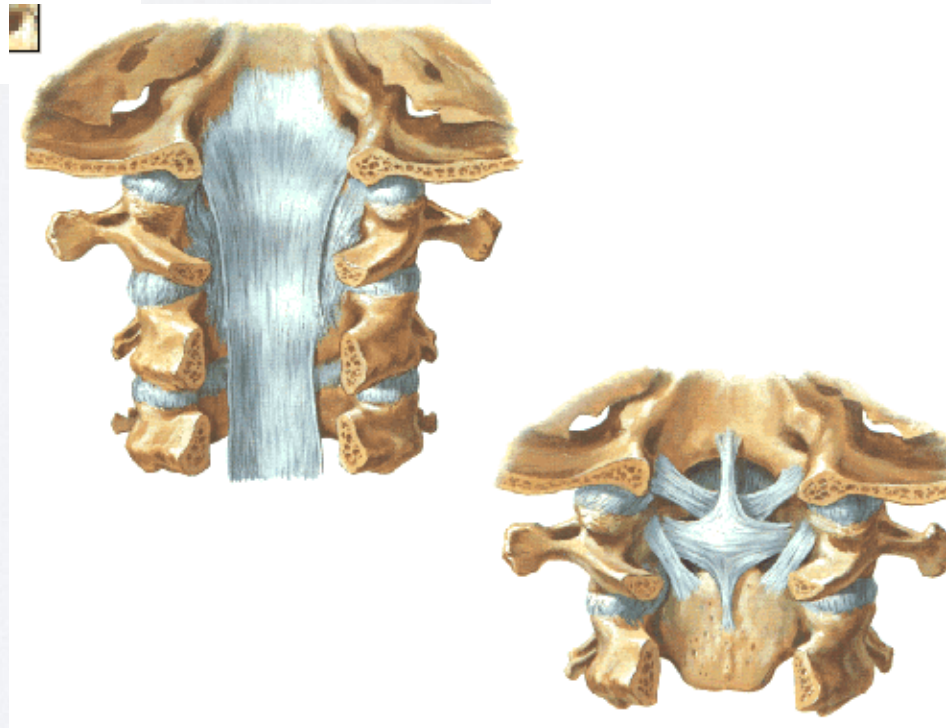
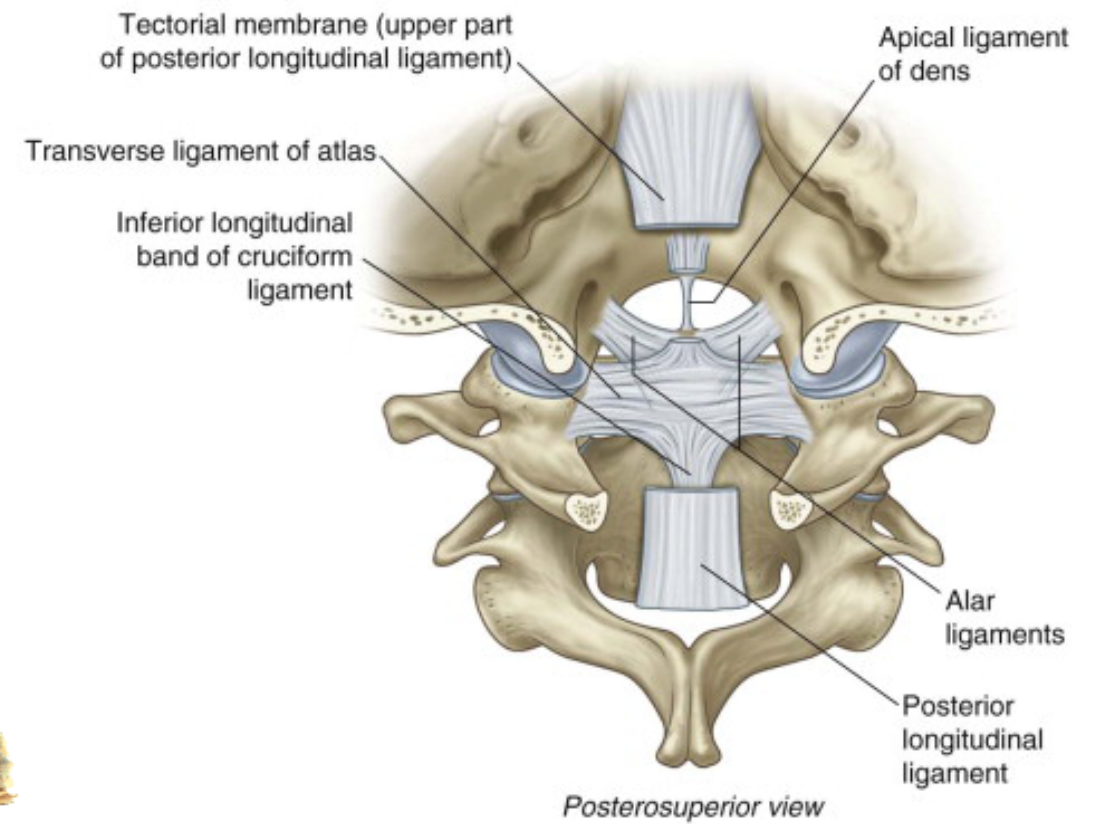


- With multiple ligaments and numerous points of attachment, the connection of the occiput with C_1 and C_2 resembles the sacrum on a smaller scale....
- And, like the sacrum, the moveable bones allow a continuous tension on the ligaments with motion in many places of the structure.

TENSEGRITY



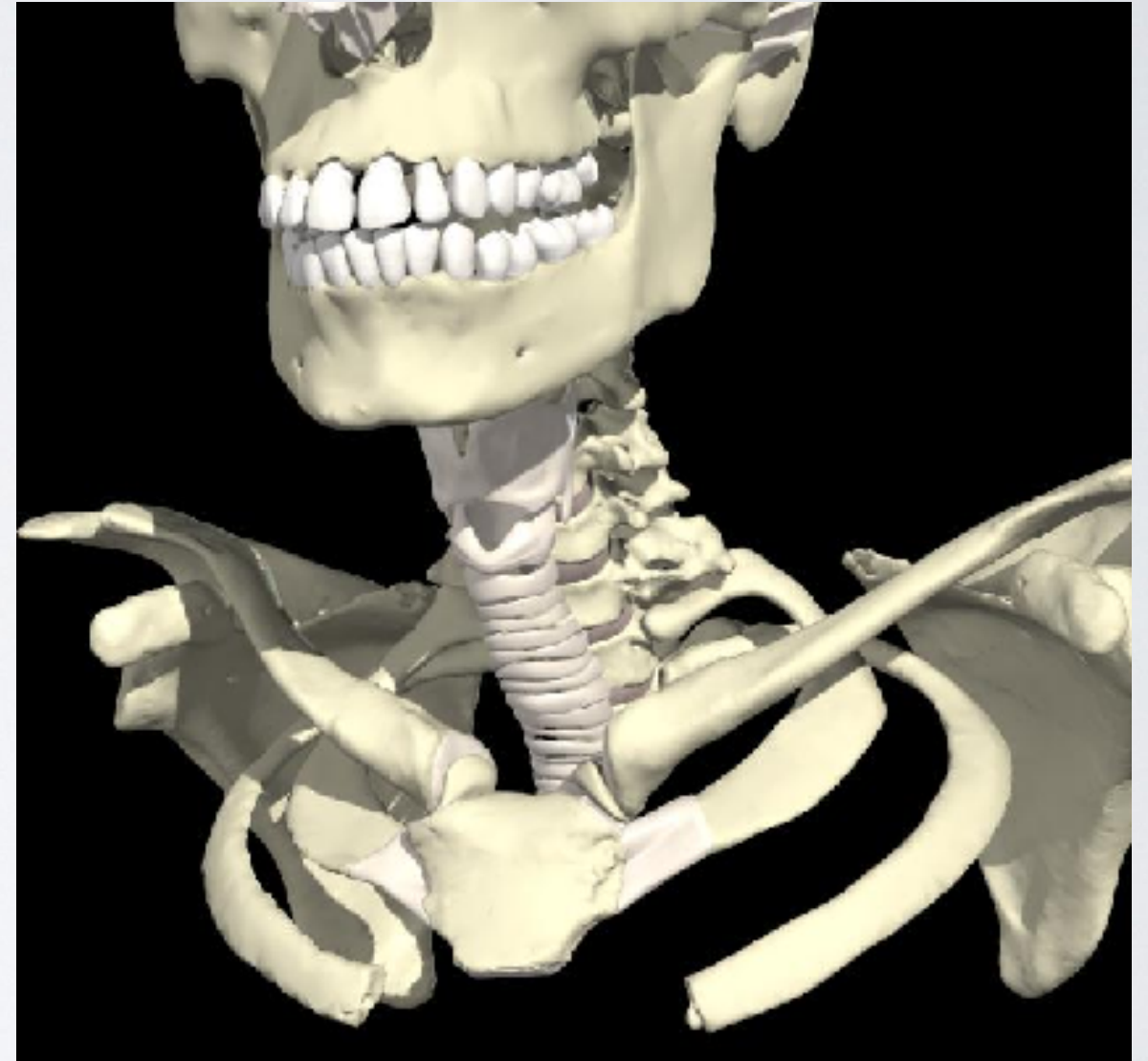
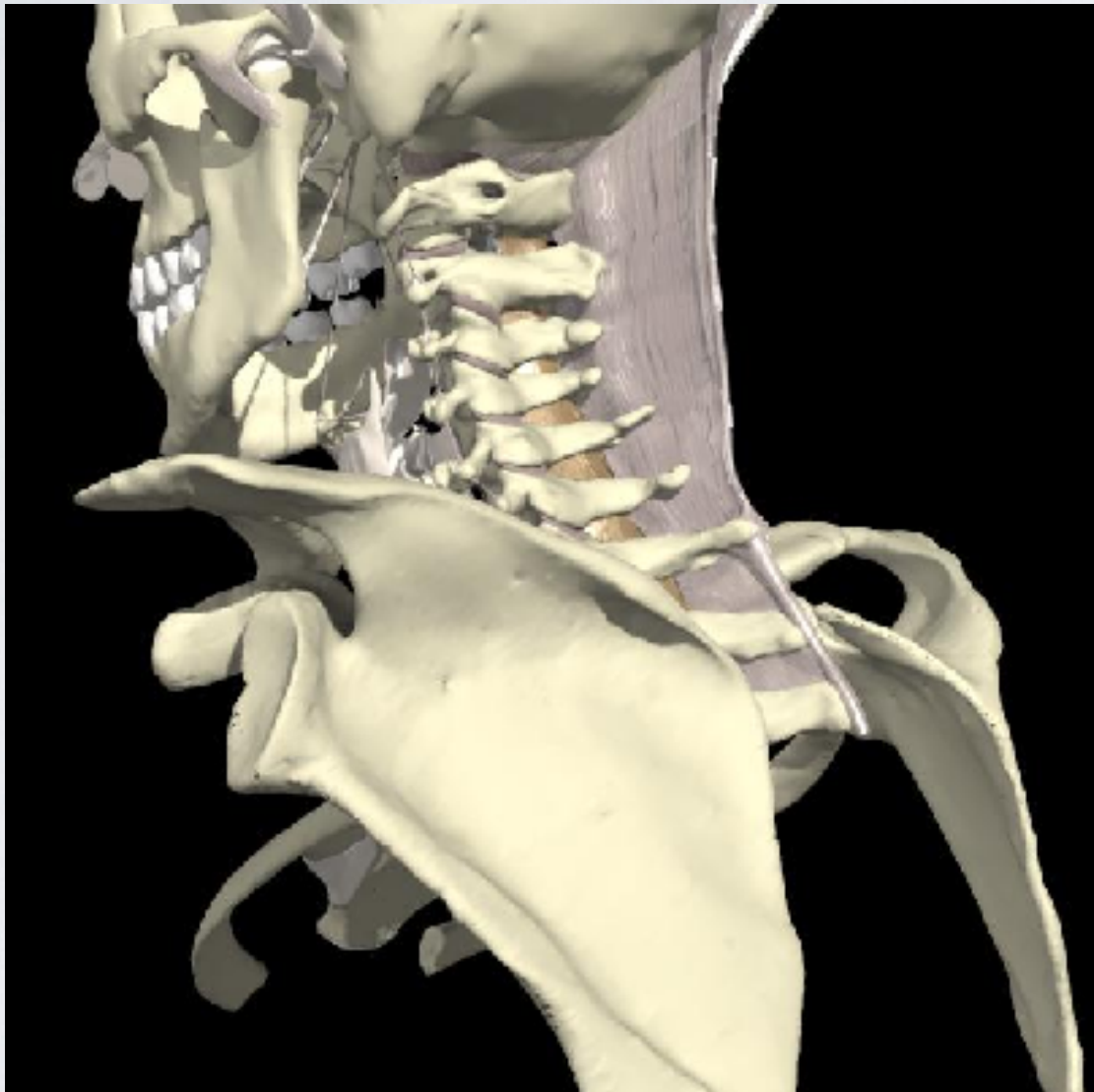
Atlas (C1 vertebra) and Axis (C2 vertebra) and base of skull



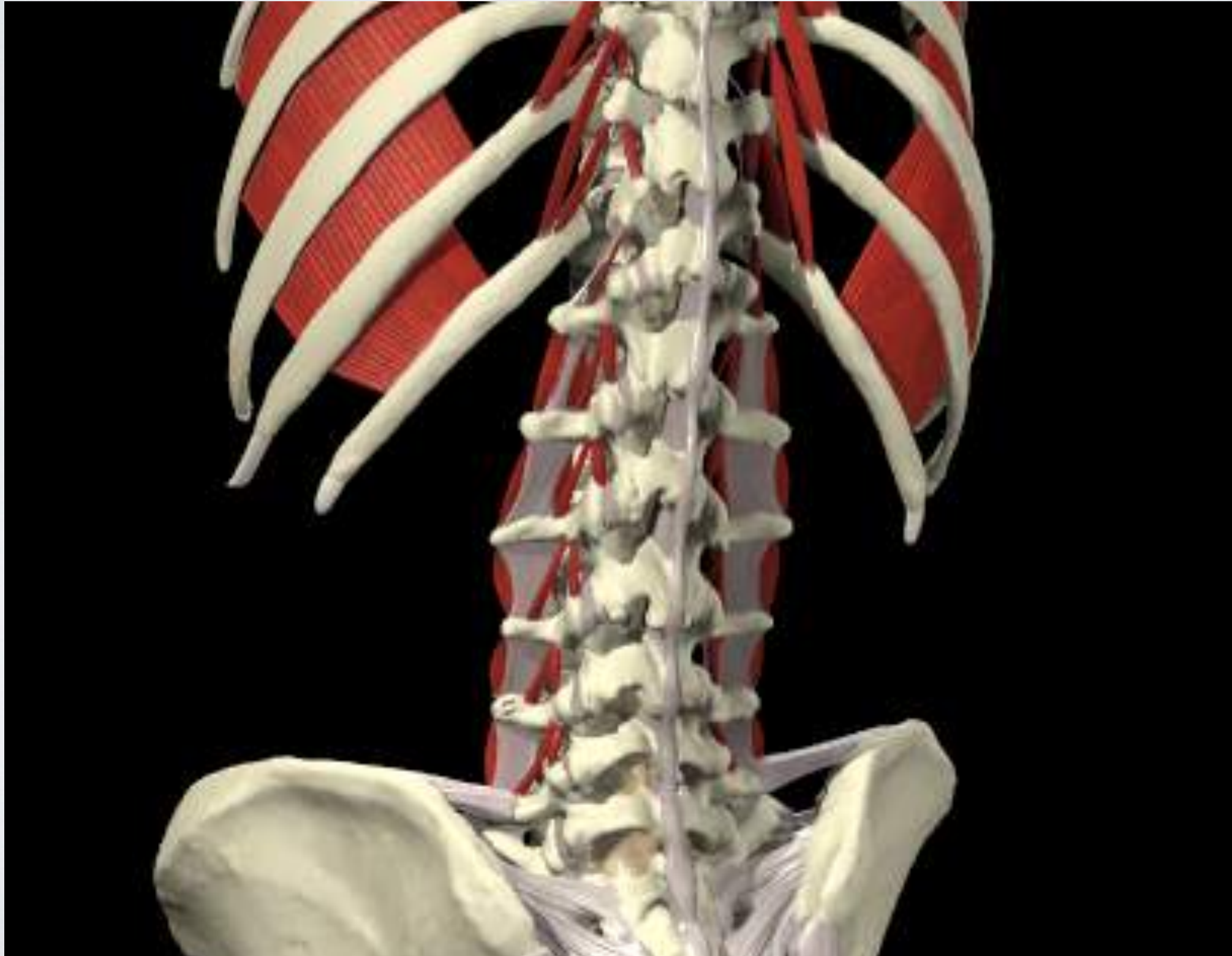
TENSEGRITY

- The uncommon ribs, 1, 2, 11 and 12 function as transition zones between the rib cage and the rest of the body. Due to their fascial attachments and unique shapes, they also connect the tensegrity subsystems of the body.

TENSEGRITY



TENSEGRITY



TENSEGRITY

Applied to Osteopathy

TENSEGRITY

- As we begin to apply tensegrity to osteopathy some interesting correlations happen....
- Notice the convergence and pull in flexion...



TENSEGRITY

- Convergence and pull in extension....
- It happens in side bending and rotation as well....



TENSEGRITY

- So it would seem that we have been using the principles of tensegrity to treat our patients since our first days of training.
- We flex or extend the spine, creating a pull on some tissue and a convergence at some point on the body or in space.
- By adding in side bending, rotation and translation we create a 3-D, human, tensegrity model of continuous pull and convergence.

TENSEGRITY

- We effect, either consciously or unconsciously, the ligaments that suspend the sacrum and other bones through manipulation.
- We impact the muscles, changing the pull on the tissues of the body.
- We change the organs, restoring balance.
- We rebalance the compression struts and tensional wires of the body.
- And we help to re-establish the tensegrity structure of the body!

TENSEGRITY

- The more we begin to understand about how to fine tune the body's tensegrity structure, the more our patients benefit, and the easier the process of diagnosis and treatment.
- As the course progresses don't forget to apply the tensegrity concept to the tissues you feel and remember that not only is everything connected in the body...

TENSEGRITY

Everything is connected via Tensegrity!

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