PAM MCKINLAY WITH DAVID HUTCHINSON
AND TERENCE SCOTT

There's a (black) hole in my bucket dear e-LISA: Experiments in Search of the Perfect G-wave in the Woven Universe

This project for Art and Space (2016) began where Art and Light (2015) left off, over a cup of coffee. In essence, another "*Conversation*,"[1] this time the subject under discussion was the effect of gravity on light. In the first instance, I was directed to the temporary exhibition at the Otago Museum in celebration of the 100 years anniversary of the publication of Einstein's Theory of General Relativity. There, amongst the demonstrations of gravitational lensing, and next to the carnival mirrors, I came across a display about Einstein's long standing prediction of the existence of gravitational waves. This was illustrated with an artist's impression of what these might look like, based on data run through a super-computer simulation. Gravitational waves are formed when large objects move through space or when objects such as black holes interact with other large objects and cause distortions in the fabric of the universe.[2] Current missions underway in search of these elusive waves include the Evolved Laser Interferometer Space Antenna more commonly called eLISA.

When we think of astronomical observatories we usually think of high-tech facilities with powerful telescopes built on isolated hill tops far from the madding light pollution of modern urban centres. Telescopes are instruments which collect light, like a bucket collects rain water. They magnify and reflect distant star light so that they appear closer when viewed (optically) through an eyepiece. Other telescopes view the universe through radio waves collected in big radio dishes, a kind of "radio eye." The radio-waves are then deciphered by radio-astronomers skilled in the arcane field of radio-data analysis. In the search for gravitational waves the observatory takes on yet another shape. The Laser Interferometer Gravitational-Wave Observatory (LIGO) is an instrument/facility built on a multi-kilometre-scale. Designed to detect gravitational-waves, as predicted by Einstein's General Theory of Relativity, LIGO uses laser interferometry to measure the minute ripples in space-time caused by passing gravitational waves in our local solar neighbourhood (as detected on Earth). It consists of two widely separated interferometers within the United States, which operate in unison to detect gravitational waves. In February this year, gravitational waves were detected for the first time and the 100 year old predictions of Einstein were proven![3] (One small ping for LIGO, one giant leap for mankind). The next step in the search for capturing the perfect gravitational wave is to attempt to make observations of gravitational waves from space. eLISA will be the first space-borne gravitational

wave observatory. Scientists think of it as a kind of radio-ear. She will also be the most expensive piece of space bling ever to leave earth containing a pair of identical 46 mm gold–platinum cubes at the centrepiece of her detection array.

Einstein's great insight was that gravity was not what Newton had thought it was. Newton's model of the universe was one in which space and time were like a stage setting, a backdrop or scaffolding within which physical phenomena occurred. His model was systematic and rational and based on notions of causality that gave rise to the principle that the force which determined the path of a falling apple on earth ought also apply to the motion of celestial bodies in space. Newton's theories are the basis of classical physics and are still very useful for most everyday situations and led to the development of the idea of the field which was important to the development of Einstein's theory of general relativity.[4]

Einstein perceived the cosmos as a fabric of woven spacetime—a fabric that has curves, with shapes and bulges dictated by the masses of the objects that lie within, and objects slipping in constant motion. These objects create curved distortions—dimples and wrinkles in the fabric of the cosmos. While we can't "see" the actual force of gravity at play causing the distortions, we can detect its presence by its effects on light as it travels through spacetime.[5]

Einstein expressed these ideas of energy-mass as an integral part of warped spacetime.

$$G_{\mu}\nu + \Lambda g_{\mu}\nu = 8\pi T_{\mu}\nu$$

Figure 1. Gravity is a force which is a result of changes of length due to space time curvature. In this field equation, the relationship can be most simply described to a non-physicist as: the left hand side tells you how spacetime curves and the right hand side tells you about the mass/energy density in that bit of space, thus this equation says the mass/energy density on the right is causing the spatiotemporal curvature on the left. The shortest distance between two points is not necessarily a straight line, but may be a curve if there is a significant concentration of energy or mass nearby.

Pressed to create a visual metaphor to help his audience understand, Einstein, replied in effect that there was no way to visually comprehend it.

> In the Theory of General Relativity we cannot use the mechanical scaffolding of parallel and perpendicular rods and synchronised clocks... Our world is not Euclidian. The geometrical nature of our world is shaped by masses and their velocities.[6]

Light is the information that we receive about the effects of these movements within the swirling fabric of spacetime.

Scientists ventured into the new mysterious depths proclaimed by Einstein and artists of the era entered the fray with incomprehensible images which defied the old facsimiles of the known, in terms of representational art. Lovers defying gravity floated about in the work of Chagall, art without image abounded in the abstractions of Kandinsky, Malevich and De Stijl, the Impressionists attempted to capture the fleeting effects of light. These are but a few examples among many of early twentieth century artists at the vanguard of mark making in search of aesthetic innovation as the classical gave way to the new in physics.

How then might an artist express a notion of inherent moving-geometry proposed by Einstein's

new ideas about gravitational fields in spacetime? We might consider Jackson Pollock's paintings of the late 1940s, famous for recording the energy exerted by his actions. There are no resolutions of "things" in his paintings. The "particles" are the visible but it is the trails from the spent forces used to execute the work that unify the 'field' across the canvas. The "entity is the field which we can only deduce by its effects on the visible."[7]

Einstein's equations meant (and still mean) that the local energetic content of our universe is absolutely equivalent to its local geometry, so if one of these two can change, the other will too. By energy Einstein meant everything that has gravitational effect, which now includes matter, light, antimatter, dark matter and everything else that has a normal decent attractive gravitational behaviour.[8]

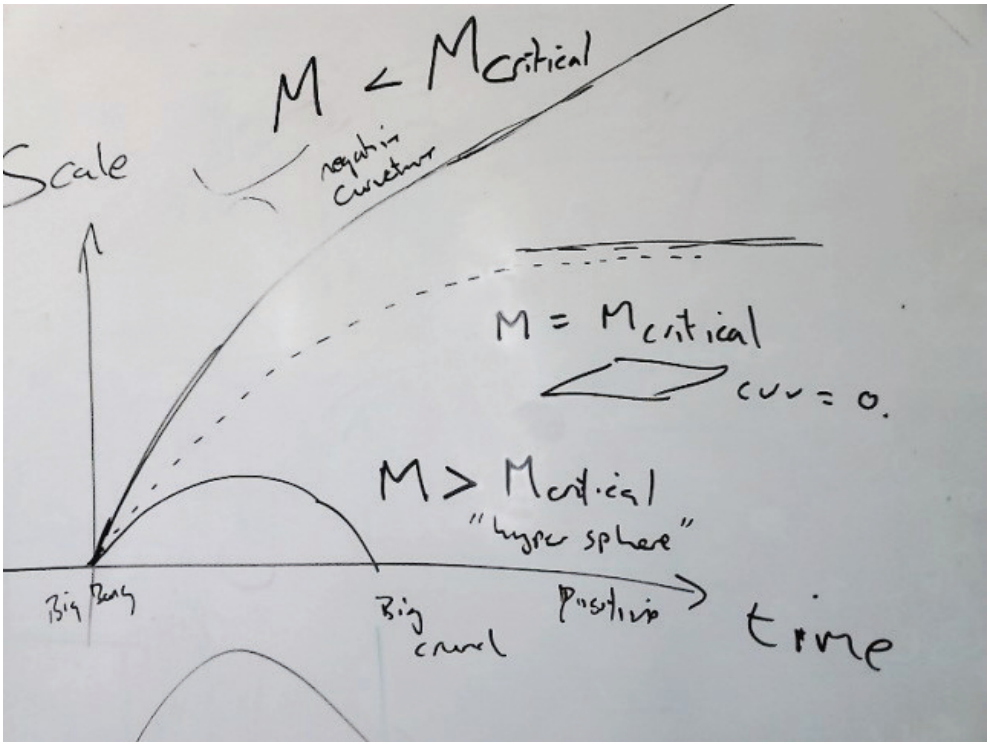


Figure. 2. The shape of the universe - the graph illustrates the observed phenomena that the universe is expanding (Hubbles Law) and explains the role of mass/energy in shaping spacetime. The curves in the diagram plot the scale of the universe against cosmic time. There are three possible models of the shape of the expanding universe - hyperspherical (positive curvature), hyperbolical (negative curvature) and flat. This diagram is a summary of the Friedman-Lemaitre equations, which predicted the expansion of the universe before it was observed by Hubble. The spacetime we are living in appears to be flat (dotted line) with a Big Bang but no Big Crunch. Comparison of the lines in the diagram indicate the shape of the universe as being "flat" in the middle (dotted) line with closed, hyperspherical universes that collapse back under their own weight below and ever-expanding hyperbolic, open universes above (note that our "present" in the diagram is a couple of centermetres from origin)[9]

BIG BANG THERAPY — DANCING IN PLATO'S CAVE AT THE EDGE OF THE EMPYREAN.

How next to represent an underlying architecture of the universe if it is not seen?

> The Tao that can be spoken is not the eternal Tao, The name that can be named is not the eternal name....[yet] one observes its manifestations.[10]

Science, which has delivered to us so much, is still in the dark. According to physicists we only know about 5% of anything about the universe. The remaining 95% of the universe is now said to be unknown. It is thought to be comprised of dark energy and dark matter. Whatever this unknown quantity is or are, it has already changed our vision of cosmology. Big Bang, the Big Crunch, the expanding universe are now all familiar ideas but given that 95% of everything is unknown, do we need a major revision of these models?[11] Do we only know the elephant by the description of the blind man describing the elephant's foot?

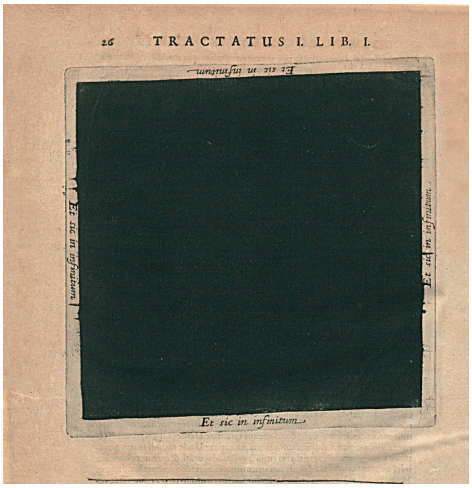


Figure. 3. "Utriusque cosmi maioris scilicet..." (trans. "Both the greater cosmos" from Robert Fludd, *The Metaphysical, Physical, and Technical History of the Two Worlds, the Major as well as the Minor.*

Figure. 4. Giusto de' Menabuoi, *Creation of the World,* Baptistery of Duomo, Padova, fresco, 1376-8

The unknown or unseen is a common trope in ancient religions, philosophy and throughout art history. In the opening plate of Robert Fludd's book on cosmology of 1617, he has drawn an image of a black square. Around the borders written on each side is, *"Et sic in infinitum"* (trans. "And so on ad infinitum"). The black square is emblematic of the unknown, and Fludd also uses it to depict the nothingness that came before the universe. In the following account he describes the emergence of the universe from the primordial abyss and proceeds through the evolution of man as a microcosm of the cosmic macrocosm and concludes with life at a cellular level as a further story within the great narrative.[12]

During the "middle ages," to the mind of a mediaeval monk the source of creation was the Empyrean. Seen depicted in the fresco by Giusto de' Menabuoi in the Baptistery of the Duomo Church, 1378, the Empyrean was the dwelling place of the supreme creator, through whose divine intervention,

order was brought to formless turmoil of the darkness of the eternal void. In Christian "mythology" order was said to be brought to this chaos by the Word, often represented as alpha and omega (in iconography as α and Ω). (Interestingly Ω is the symbol used in the Friedman-Lemaitre equations where the value above or below 1 determines the shape and fate of our universe.)[14]

If we retreat further back in time we encounter another beginning story, where everything is personified in the form of "Chaos." In Olympian mythology there were no things, no forms, no substance and no time. In the beginning there was just a moment of pure energy.[15] The unknown was perceived of as being chaotic, in constant turmoil, and the pivotal moment of creation as being climatic and momentous. The Greco-Roman genesis story is retold as an old-world divine genealogy.

From the western world to the wide reaches of Asia and the Pacific, all cultures also tell similar and momentous creation stories. In Aotearoa the details of the creation stories vary among iwi but are told within the context of genealogy. In essence they tell the story of the world back beyond the first ancestor and going back before time where there is first the creator, root-cause, followed by the void, the cold, the night and life principle.[16]

The first recorded proposition we have (in the Western world) of an instantaneous moment of creation came about in the *Summa Theologiae* written by St Thomas, 1266. He believed that the moment of origin was instantaneous and unknowable "We may believe that there was a beginning to the World, but we can neither prove it nor explain it," he said. He went on to say that the remaining processes of creation were an exercise in shaping the substance created at the moment of *origin*.[17] As far back as Hesiod's *Theogony* and Plato's *Timaeus,* notions had been explored of what these shaping processes may have been and that the act of Creation must have been guided by some overriding super-geometric principle.[18]
"Gravity is bent space," says David Hutchinson. It is the invisible anatomy of the universe. Gravity is the experience of the geometry of the fabric of the universe.

> Spacetime tells matter how to move; matter tells spacetime how to curve.
> (John Archibald Wheeler)[19]

Although we can't see gravity, we can learn about it from its effects. As in Plato's cave analogy, we see the "effects" of gravity as a play of shadows and echoes cast by forces that, as for Plato's prisoners, we cannot see.[20] Gravitational waves are the so called ripples in the fabric of spacetime. The curves are determined by what lies within. Light gives us an illusion of gravity—light is the information—casting the shadows in Plato's cave.

THE WOVEN UNIVERSE, FABRIC OF THE COSMOS, WRINKLES IN THE FABRIC OF SPACETIME

Techne was the goddess of practical knowledge and from where we get the name *tikein* to create and technique (the way we create). *Techne* served as the muse for the sciences as well as for art.[21] In the first response to the project I attempted to create photographs of simulated gravitational propagation waves in an imagined model of a geometric universe (spacetime), photographing the effects on a lattice being acted upon, from all directions, by unseen submerged forces in water, observed at various angles of raking light. This was done in my Backyard Universe simulated

Gravitational-wave Observatory (and because we all like an acronym—BUGO). Of course space is not water: it is, well, it is "space." The negative image of the photographs with reduced opacity came close to simulating the effects of a more vapourous system with what looked like smoke injected into an invisible system wending its way along the slip trails.

The idea of simulating "ripples" in the fabric of spacetime in a fluid environment was a useful analogy because ripples in water are called *gravity waves* - internal waves which are generated within a fluid medium, at the interface between two media when the force of gravity or buoyancy tries to restore equilibrium. What I describe as slip trails, can be thought of as streaklines, a term used in fluid dynamics - imaginary lines in a fluid flow that help to better understand flow. Fluid flow is characterized by a velocity vector field in three-dimensional space, within the framework of continuum mechanics.[22] (Note: "gravitational waves" are waves of gravity, ripples in spacetime: "gravity waves" are waves in fluid surfaces caused by gravity, but the turbulence analogy was a

Figure 5. Pam McKinlay, *BUGO:73* photograph.

useful starting point for this exercise.)
Fabric is a commonly used metaphor when describing spacetime because of the weaving analogy and the mental image we get of a pliable woven lattice, usually that of a plain weave. The woven panels were made by feeding the visual "data" created in the first part of the project, in the photographs, into an analog computer (hand loom). Following the philosophy of the Bauhaus weavers that "Only work at the hand loom allows the kind of latitude for an idea to be developed..."[23] In weaving, the elements are subject to the laws of plane geometry and time. (Woven fabrics are a locus of time in that they both make and record time, by the time they take to create, and are a continuation of technique across time. The hand loom being the embodiment of a kind of time travel). In the second part of the project I made more experimental weavings of the photographs.

Both parts of the fabric were woven flat, but once the warp tension was released they relaxed into a highly dynamic and unpredictable dimpled surface. One panel was woven in black weft on monofilament warp using a freedom weaving technique. The resulting fabric appeared flat and mostly featureless until back-lit at which point subtle shading became evident, caused by variation in cramming and spacing both during the weaving process and controlled manipulation of individual picks in a follow up process while the panel was still on the loom. In the second panel I wove the negative photographic image using an eccentric tapestry technique to provide a visual counterpoint (monofilament weft on monofilament warp with random inserted wool wefts as the tapestry design element).

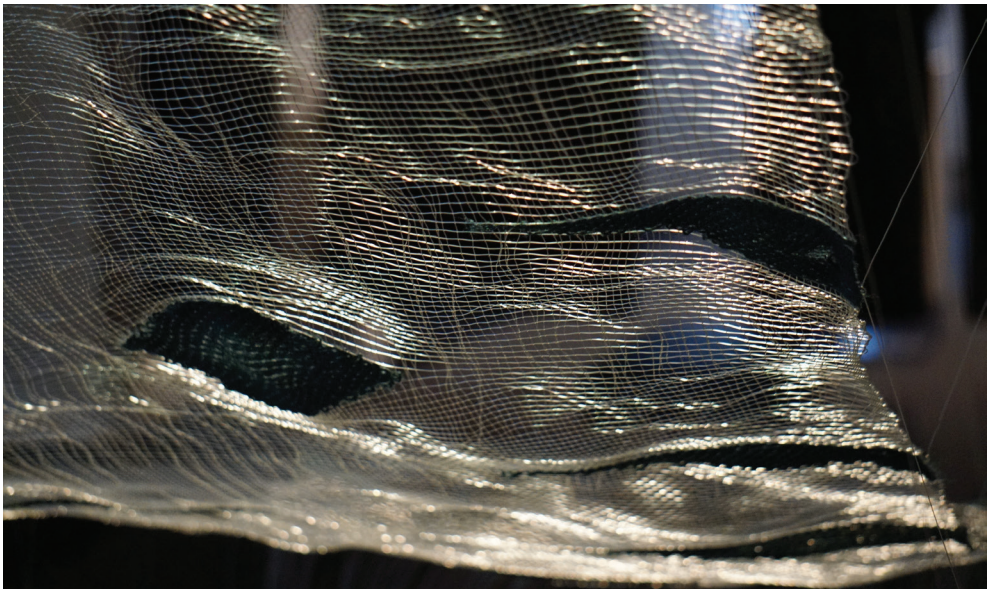
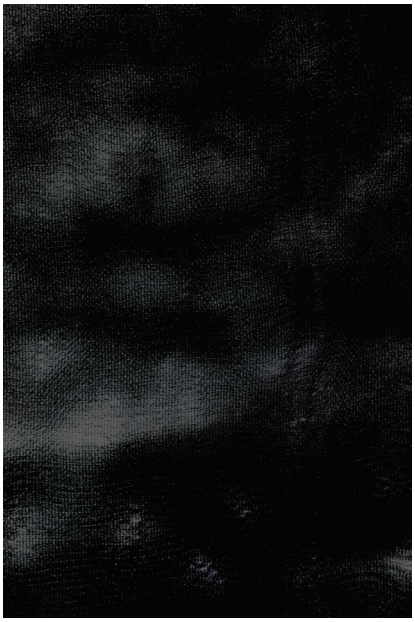
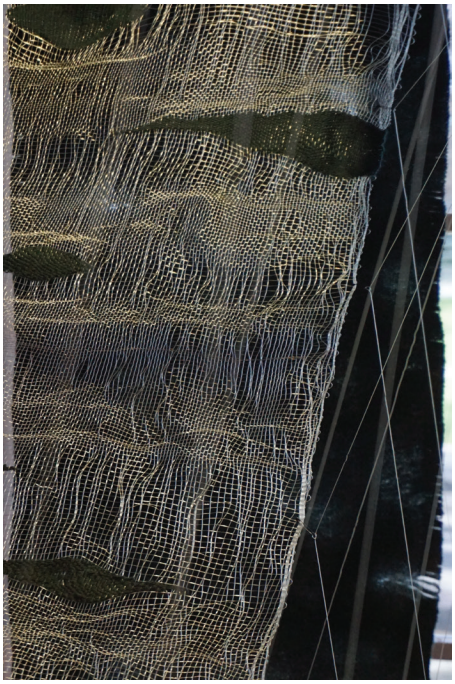


Figure. 6. Detail from one of the weavings based on the reversed negative image of one of the photographs, monofilament and wool, dimensions variable.



Figures 7 and 8. Pam McKinlay, woven panels from *In Search of the Perfect G-wave in a Woven Universe* (left) *Big Bang Therapy — Dancing In Plato's Cave at the Edge of the Empyrean,* (right) *There's a (black) hole in my bucket e-LISA,* hand woven panels, monofilament and wool, 2500 x 800.



Figs 9-11. Pam McKinlay, *In Search of the Perfect G-wave in a Woven Universe*. installation view, Art and Space Exhibition, HD Skinner Annex, Otago Museum, Dunedin, 16 September-2 October, 2016.

The two pieces were displayed suspended within a caternary system—a tensioning frame featuring pulleys and small weights and the weaving as a counterweight body—a reference to the classical physics at the heart Newton's mechanistic model of the universe and the challenge thrown down by Einstiein's conceptual breakthrough with regard to the curvature nature of spacetime. The strings were free to move on hand made mini-pulleys, and the weights that fell and readjusted, as well as the fabric, were responsive to the adjustments from movements within the system. The fabric buckled and puckered according to its own nature (strand memory) and the constraints of the heavier inserted woollen elements around which the system also moved and accommodated itself. The angle of lighting was a critical factor. The pieces appeared flat unless viewed in raking light whereupon the surface moved and shimmered in the folds and dimples: a play of shadow and light and a dramatic three-dimensional moiré effect. In places the weave seemed to disintegrate and disappear entirely in the valleys.

BACK TO THE BEGINNING

Our world views are culturally conditioned. Often our thoughts and logic are codified in language comprehensible only to associates and kindred spirits who hold the knowledge necessary to decipher and read the full meaning. Science codifies its thoughts in equations—what appear to the uninitiated as collections of random letters, symbols and numbers in configurations of uncommon fractioning, appear to the scientific mind as intelligent linear sequences of flowing causality within elegantly defined parameters. Over subsequent cups of coffee the physicists in this project generously unwound the meanings of mathematicity built into the equations and the narrative became clearer whereupon I rewove it in another form in an attempt to capture the movement, the weight, the tensions and the light of the underlying story. It is a modest representation of the "shaping" chapter, as described by St Thomas, from the greatest story ever told.

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2. Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (New York: William Morrow and Company, 1986) 184. A black hole is an area of space which appears absolutely black because the gravitation there is so intense that not even light can escape into the surrounding areas. Gravitation is neglible on the laboratory level, but quite important when bodies of large mass are concerned. Therefore, the exploration of black holes naturally became a joint effort of physicists and astronomers.
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6. Leonard Shlain, *Art and Physics: Parallel Visions in Sace, Time and Light* (New York: William Morrow and Co. Inc., 1991) 343.
7. Ibid. 248.
8. Christophe Galford, T*he Universe in your hand: A Journey through Space, Time and Beyond* (London: McMillan, 2015) 341.
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10. Lao Tzu, *Tao Te Ching*, Chap. 1, Trans. Derek Lin, http://www.taoism.net/ttc/chapters/chap01.htm (accessed 17 Sep 2016).
11. Shlain:1991, 340. Composition of the universe is thought to be dark energy 72% dark matter, 23% and the matter we know (including light) 4.6% Everything we know is 4.6% total — the rest is unknown.
12. Robert Fludd, *The Metaphysical, Physical, and Technical History of the Two Worlds, the Major as well as the Minor*. Fludd published his work between 1617 and 1621. Page 26. Image source https://wellcomeimages.org/indexplus/image/L0060919.html (accessed 23 October, 2016).
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14. The critical density (omega) is 1, so variations with omega larger than 1 are closed (Big Crunch) and smaller than 1 expand for ever.
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16. Rev. Māori Marsden, *The Woven Universe*, ed. Te Ahukaramu Charles Royal, (Otaki, Te Wanganga-o-Raukawa, 2003) 31-33.
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20. Plato, C5th BC, "The Allegory of the Cave," *Republic VII*, In the allegory, Plato likens people untutored in the Theory of Forms to prisoners chained in a cave, unable to turn their heads. All they can see is the wall of the cave. Behind them burns a fire. Between the fire and the prisoners there is a parapet, along which puppeteers can walk. The puppeteers, who are behind the prisoners, hold up puppets that cast shadows on the wall of the cave. The prisoners are unable to see these puppets (the real objects passing behind them). What the prisoners see and hear are shadows and echoes cast by objects that they do not see. https://faculty.washington.edu/smcohen/320/thforms.htm (accessed 17 Sep, 2016).
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