# Complexity & Design

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# Events

- 12 January 2005
  **Complexity & Design Seminar**
  **On ten principles of complexity**
- 7 October 2005
  ***Art, Complexity & Design Workshop***
  John Hamilton Frazer (Video)
  ***Interfacing with Evolution: towards a self organizing Architecture***
  Luc Steels, (Video) University of Brussels (VUB AI LAB), Sony Computer Science Laboratory, Paris
  ***'Kovalevsky's top' and the Theatre of Complexity"***
  Jeff Johnson
  Panel of Artists: Michael Petry, Mateo Willis and Gail Troth

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# Complexity & Design

Two examples
- Millennium Bridge
  - Engineering complexity
  - Social complexity
- Harrison's clocks
  - The evolution of design

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# *Millennium Bridge*

- **Some 80,000 people crossed the bridge on its opening day and those on the southern and central spans detected vibrations.**

  **The bridge began to sway and twist in regular oscillations. The worst of the movement occurred on the central span where the deck was moving by up to 70mm. The frequency of the oscillations increased, leaving people unnerved and unsteady.**
- The engineers insisted the bridge wouldn't fall down but closed it completely after an attempt to limit numbers proved unworkable.

  Engineers discovered that the sideways forces of the pedestrians' footsteps created a slight horizontal wobble in the bridge.
  As the structure began moving, pedestrians adjusted their gait to the same lateral rhythm as the bridge.
- **The adjusted footsteps magnified the motion - As more pedestrians locked into the same rhythm, the increasing oscillations led to a dramatic swaying motion.**

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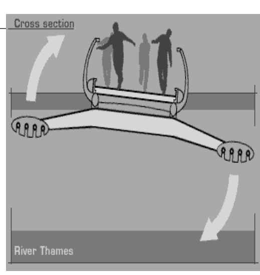
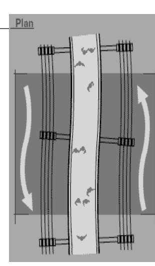
# *Millennium Bridge*

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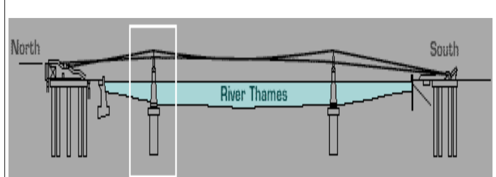
# Elevation

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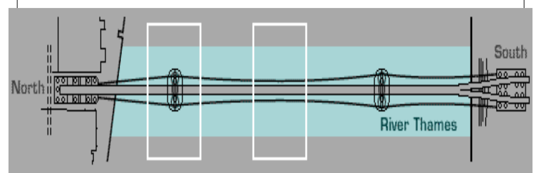
## Solution

- 1st proposal: to stiffen the structure and therefore reduce the chances of movement. 2nd proposal: to limit access and modify how people crossed the bridge by using street furniture such as bollards and barriers.
- The ***designers*** ruled out both of these options because they would have changed the shape and look of the bridge.
- Instead, the ***engineers*** decided on damping mechanisms - giant shock absorbers which limit the bridge's response to external forces.
  Dampers are used in bridges and buildings around the world, especially in areas prone to earthquakes.
  Also dampers would be beneath or within the structure and therefore generally hidden from public view.
- **The engineers needed some dampers to counter movements of less than 1mm and others to counter much more powerful forces.**
  **The team decided to use two systems in tandem: Viscous dampers, similar to car shock absorbers, and tuned mass dampers, a large mass stiffened by springs.**





## Plan







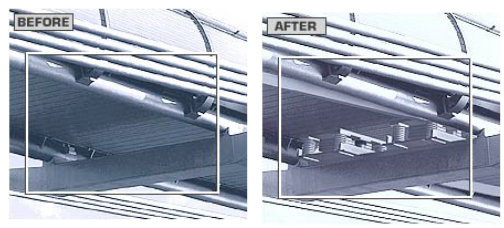

## Dampers

- Tuned mass dampers have been placed in a regular pattern between the underside of the deck and the top of the transverse arms. These absorb vertical movement.
- There are additional tuned mass dampers underneath the central span. These are designed to restrict the worst of the horizontal movement.





*Underneath the deck*








Theories

*Natural sciences*

Dissipative structures
chemistry-physics (Prigogine)

Autocatalytic sets
evolutionary biology (Kauffman)

Autopoiesis (self-generation)
biology/cognition (Maturana)

Chaos theory

*Social sciences*

Increasing returns
economics (B. Arthur)

*Generic characteristics of complex co-evolving systems*

**self-organisation**

**emergence**
**connectivity**
**interdependence**
**feedback**

**far from equilibrium**

**space of possibilities**

**co-evolution**

**historicity & time**

**path-dependence**

***creation of new order***





## Engineering Complexity

- The pedestrians had been resonating with the bridge, and inadvertently amplified its movements. People unconsciously synchronized their steps as they walked, and the more they did, the more the bridge wobbled. As the bridge wobbled, pedestrians spontaneously adjusted their gait even more to conform to the movements of the bridge.
- Strogatz* calls it "unintended human synchrony caused by **positive feedback**".
- Academics in the US, Britain and Germany have developed mathematical models and equations to explain the dynamics of the bridge and the people on it. According to their analysis, the bridge was steady with 150 people on it, but began to sway when the number increased to 160.

**REF: **Steven H. Strogatz** 'Sync: The Emerging Science of Spontaneous Order' Hyperion Press, 2003 (Strogatz is Prof. of Applied Mathematics at Cornell – 2nd example: fireflies*

## Engineering Complexity

- The structural wobbling and the crowd synchronization "**emerge** together as dual aspects of a single instability mechanism once the crowd reaches a critical size."
- Models and calculations are reported in the 3 November 05 issue of Nature.
- Their work is expected to help engineers understand the unanticipated stresses on bridges, and better estimate stabilization needed.
- Furthermore, this work delves into a new area of mathematical exploration that deals with **nonlinear phenomena** and the profound philosophical questions of how **self-organization** happens and how **order can emerge**.





## *SOCIAL COMPLEXITY*

- **The *designers* insisted that the bridge's "elegance" had to be protected, meaning that the engineers had to find a solution that was also aesthetic.**
- The *engineers* say the solution does not affect the side elevation of the bridge as it is seen from the river and banks.
- **But, inevitably, the engineers could not hide all the dampers. Some are now visible on the piers and the southern ramp.**





## In Complexity Terms

- The designers and engineers influenced each other (while working within certain physical constraints)
- ***Short term adaptation -> longer term co-evolution in relationships, approach, future design?***
- What was the collaboration environment like?
- Could it have been otherwise?
- What difference would it have made?





## Some Questions

- The sideways motion had been seen before, most notably in 1975 on the Auckland Harbour Bridge in New Zealand
- Why wasn't the problem identified earlier?
- What are the conditions for an enabling environment for greater collaboration, safe design, etc ?





## The Problem of Longitude

- By 1714, the problem of longitude at sea still defied solution, both navigation and cartography suffered
- Parliament voted to offer a reward "for such person or persons as shall discover the Longitude" and the Board of Longitude was set up (scientists and admirals) to evaluate entries
- Dead reckoning, magnetic declination, and Jovian satellites had been discarded, and the lunar method remained an uncertain prospect
- One other possible approach - a highly accurate mechanical clock to be carried on ship. The clock would keep the time of the prime meridian.
- By comparing this time with the local time at sea or on some distant shore, it would be possible to know one's longitude relative to the prime meridian.
- Newton "...by reason of the Motion of a Ship, the Variation of Heat and Cold, Wet and Dry, and the Difference of Gravity in Different Latitudes, such a Watch hath never been made"





## The Evolution of Design

- John Harrison improved the pendulums: They were made of iron or steel rods, which contracted in the winter, making the clocks run fast, and expanded in the summer, causing the clocks to lose time. Harrison's invention eliminated this fault. It consisted of nine alternating steel and brass rods, so assembled that the different expansion and contraction rates of the two metals canceled each other out.
- 2nd invention: the "grasshopper" escapement, a new type of control device for the step-by-step release of a clock's driving power. His escapement was almost frictionless and required no oiling; it thus pointed the way to further improvements in clockmaking.
- Harrison, spent seven years building his "Number One" clock H1 - 1735
- Large and heavy, standing almost one meter tall. Harrison had eliminated as many moving parts as possible. Instead of using a pendulum, which had proven unreliable at sea, he designed a system of two large brass balances connected by wires. The motions of the two balances, of equal weight, were always opposed so that the effect of a roll of a ship on one would be counteracted by the other.

## H1



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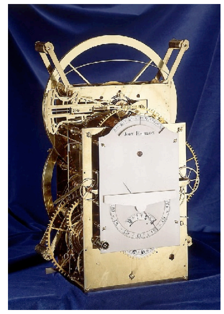

## H3

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## Harrison's Marine Chronometer H3

H3 incorporated two inventions of Harrison's -

- a bimetallic strip, to compensate the balance spring for the effects of changes in temperature
- a caged roller bearing, the ultimate version of his anti-friction devices.

- Both of these inventions are used in a variety of machines today
- Despite these innovations, work on H3 seemed to lead nowhere and its ultimate role was to convince Harrison that the solution to the longitude problem lay in an entirely different design.

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## H4

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## H4

- H4 is completely different from the other three timekeepers.
- Just 13 cm in diameter and weighing 1.45 kg, it looks like a very large pocket watch.
- Harrison's son William set sail for the West Indies, with H4, aboard the ship *Deptford* on 18 November 1761. They arrived in Jamaica on 19 January 1762, where the watch was found to be only 5.1 seconds slow!

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## K1 and Success

- Captain Cook set out on his second voyage of discovery with K1, Kendall's copy of H4. He returned in July 1775, after a voyage of three years, which ranged from the Tropics to the Antarctic. The daily rate of K1 never exceeded 8 seconds (corresponding to a distance of 2 nautical miles at the equator) during the entire voyage and Cook referred to the watch as

  ...our faithful guide through all the vicissitudes of climates

- It is not known for certain whether Harrison knew of this success, but Cook's voyage proved beyond doubt that longitude could be measured from a watch.
- John Harrison died almost one year after Cook's return, on 24 March 1776, in his house at Red Lion Square, London. It was his 83rd birthday.

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## Some Complexity Ideas

- Far from equilibrium
- Exploration of space of possibilities
- Feedback
- Emergence
- Self-organisation
- Co-evolution
- Creation of new order



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## Some Complexity Ideas

- The reward in 1714 pushed the existing conditions to a *far-from-equilibrium* position – existing ways of thinking did not work – they had to change
- Second major breakthrough came with H4
- In between periods of gradual development
  - Harrison had worked on the clock for >60 years
  - Two types of evolutionary process: punctuated equilibrium?
  - Creation of new order
- Environment for innovation -> evolution of design/technology?

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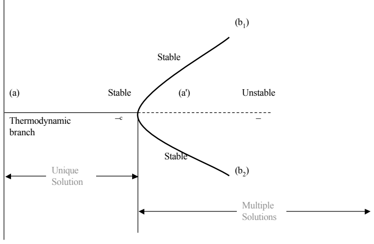


Bifurcation Diagram
(from Nicolis & Prigogine, 1989, p72)
Showing how a state variable X is affected when the control parameter _ varies. a unique solution *(a)*, the thermodynamic branch, loses its stability at $\_{c}$. At this value of the control parameter new branches of solutions *($b_1$, $b_2$)*, which are stable at the example shown, are generated.

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