Earth is an ecosystem
One square foot (David Liittschwager)
A Polynesian reef
The biosphere

• What is it to be alive?
  – To eat
  – To reproduce

• The dilemma of life: cooperation or conflict?

• Who carries the dilemma?
  – The individual
  – The species
  – The gene
Mathematics and biology 1: probability theory

- If children are a mixture of both parents, how come we observe such diversity among individuals instead of an averaging out?
- Mendel (1866): traits are discrete and not continuous (alleles)
- A computation by Hardy et Weinberg (1908)
The Hardy-Weinberg model

• Two alleles $A$ et $B$. Each individual has two chromosomes, so $AA$, $AB$, et $BB$ are present.

• First generation: proportions $x, y, z$. So $A$ for instance has frequency $x+y/2$.

• If mating is random, next generation will have $A$ et $B$ with frequencies $p = x+y/2$ et $q = z+y/2 = 1-p$.

• So $AA$, $AB$, and $BB$ will be observed with frequencies $p^2$, $pq$ et $q^2$ which are now stable.
Mathematics and biology 2: Game theory

• The prisoner's dilemma: A and B are suspected of a crime. They are asked separately to tell on the other
  – If one does, he gets out but the other gets a 5 year sentence
  – If both do, both get a 10 year sentence
  – If none does, both get a 1 year sentence
• One-shot game: you are always better off telling
• Repeated games (evolutionary dynamics):
  – Cooperation vs Betrayal in a population
  – The game of sex
Earth is a society
Earth as we see it
Mathematics of society

- Since the industrial revolution, the time scale of history is much shorter than the time scale of biology: we cannot wait for evolution to solve our problems
- The rationality axiom: humans have a reason for everything they do
- For human beings, the dilemma of life takes a particular form: individual rationality or collective rationality: what is good for me may not be good for society.
Urban transportation

• Driving from A to B takes 2 H when everyone is out, 30 mn if the road is empty
• City Hall install a bus line: the bus takes 50 mn if there are no cars on the road, 2H 20 mn if all the cars are out
• If everyone takes the bus, everyone gets from A to B in 50mn
• If everyone drives, everyone gets from A to B in 2H
• What will people do?
The lemmings

• A society of rational people deliberately chooses to spend 2H getting to work every day when they could do it in less than half the time

• General problem:
  – Public goods and taxes
  – Not in my backyard
  – Climate change
Social engineering

- City Hall installs an underground line which connects A to B in 50 mn, regardless of traffic on the road
- If everyone takes the metro, everyone gets from A to B in 50 mn
- If everyone takes the car, everyone gets from A to B in 2 H
- What will people do?
Earth is a spaceship
The lights
No pilot on board

- Earth is a spaceship which carries mankind in the interstellar vacuum
- The crew has taken command
- We have explored the ship, we don't understand it fully, but we have already spotted some weak spots:
  - End of biodiversity
  - Climate change
- The speed of changes is such that mankind cannot rely on the inboard computer to correct them
A cause for worry

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Carbon dioxide concentration (ppmv)
The case of climate change

Some relevant factors:

- Variations of the Earth's orbit around the Sun
- Solar activity
- Volcanic activity
- Internal processes (clouds, icecaps, winds, currents)
- Biological activity (forests, plankton, herbivores)
- Emissions (aerosols, greenhouse gases)
The carbon cycle
Climate models

- Climate models are complex: there are many relevant factors, many equations, many time scales, many variables to compute and many to enter
- A new type of science: such models require the collaboration of thousands of scientists with different backgrounds (IPCC)
- Standard difficulties due to complexity and chaos:
  - Many models
  - Many runs
Les obstacles à la prévision:

- Les phénomènes de seuil: des changements continus peuvent induire des catastrophes.
- Le progrès technologique: effets ambigües
  - Effet rebond
  - Paradoxe vert
- Ce que l'on ne soupçonne pas
  - Epidémies
  - Guerres
The human factor

• Alternative climate policies:
  – Business As Usual (BAU)
  – Nuclear energy
  – Transition to gas

• Individual rationality:
  – Green paradox
  – Bouncing back

• Noncooperative solutions
  – Famines
  – Wars
BAU / transition towards gas

• **(Cryosat)** From 2030, the Arctic Ocean will be icefree in the summer

• **(International Energy Agency)** By 2100, on current trends, mean temperatures will increase by 6 degrees Celsius

• **(World Bank)** An increase of 4 degrees would be catastrophic. Mediterranean summers will be hotter by 9 degrees Celsius

• As of May 2013, concentration of CO\(^2\) in the atmosphere has reached 400 ppm
What should be done

• The risk is very unevenly distributed
  – North vs South
  – Rich vs poor
  – Environment vs development
  – The present generation vs the future ones
  – Mankind vs the rest of the biosphere

• There will be losers and winners, and there is no consensus on what should be done
What could be done?

- Climate policies are the hardest to implement
  - No agreement on objectives
  - The commitment problem (IE)
  - The prisoner's dilemma
  - Effects have great local variation
  - Effects are far away into the future
  - Predictions are uncertain
What will happen

• **Non-cooperative solutions**
  - BAU, with adaptation and mitigation
  - Wars, pandemics and famines

• **Cooperative solutions**: this would require the emergence of new social norms, more or less inclusive:
  - Everyone alive today
  - Future generations
  - Other living species
  - Earth itself (Gaia)

• Where are they going to come from?
What is mankind?