COMPLEX DYNAMIC PHENOMENA IN ENVIRONMENTAL PLANNING AND MANAGEMENT

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1. ENVIROMENTAL MANAGEMENT AND NONLINEAR DYNAMICS
   An overwiew of the most typical problems one encounters in enviromental planning and management. Emphasis on relationships with nonlinear dynamics.Further reading: *Journal of Enviromental Management* (1996), 48, 357-373.

2. THE PROBLEM OF FLOATING PLANTS IN RESERVOIRS
   Description of the problem through a model of competition between floating and submerged plants. Analysis of the model: alternative stable states. Bifurcation analysis and derivation of possible control actions. Analysys of the history of Lake Kariba on the Zambesi river.
   Further raeading: *PNAS* (2003), 100, 4040-4045.

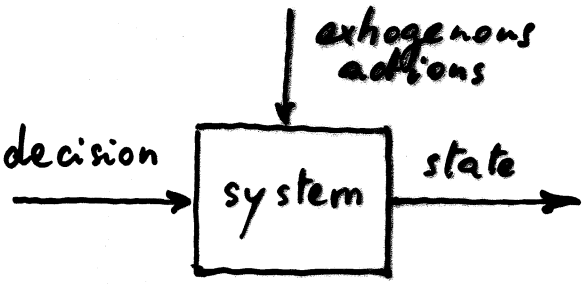
3. FOREST EXPLOITATION AND ACID RAIN: A DANGEROUS MIX
   Description of the problem through a series of minimal models. Existence of catastrophic bifurcations (forest collapse). Cusp bifurcation: negative synergistic effect of acid rain and exploitation.
   Further reading: *Vegetatio* (1987), 69, 213-222
   Appl. Math. Modelling (1989), 13, 674-681
   Theor. Pop. Biol. (1998), 54, 257-269.

4. THE RECLAMATION OF EUTROPHIC WATER BODIES
   Description of the problem in terms of minimal models involving algae, zooplankton and planktivorous fish. Analysis of the bifurcations of the model: the appearance and disappearance of clear-water regimes. Biological control.
   Further reading: *OIKOS* (1997), 80, 519-532.

5. TOURISM SUSTAINABILITY: AN OVERVIEW
   The three components of the problem: tourists, environment and facilities. Detection of possible scenarios. Profitable, compatible and sustainable policies. Adaptivity. The case of alternative classes of tourists and of diversified investments.
   Further reading: *Conservation Ecology* (2002), 6(1): 13 [online].
   Chaos and Complexity Letters (2004) first issue (in the press).

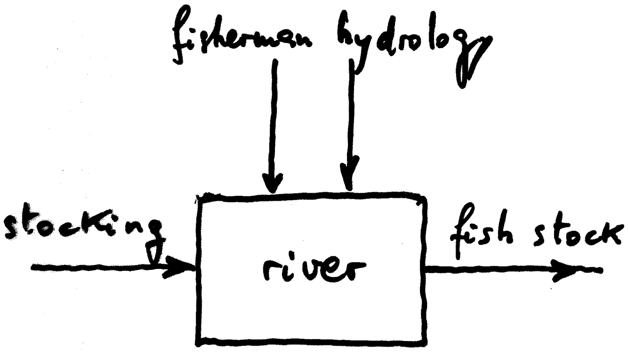
6. ENRICHMENT AND YIELD MAXIMIZATION
   Exploitation of renewable resources. Enrichment and mean yield maximization. Analysis of the case of tritrophic food chains. Optimality at the edge of chaos. Derivation of management rules.
   Further reading: *Am. Nat.* (1997) 150, 328-345
   Bull. Math. Biol. (1998) 60, 703-719
   Ecol. Lett. (1999) 2, 6-10
   J. Math. Biol. (2002) 45, 396-418.

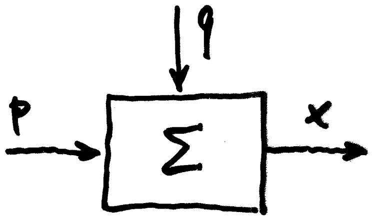
PLANNING



select the best decision and keep it fixed forever

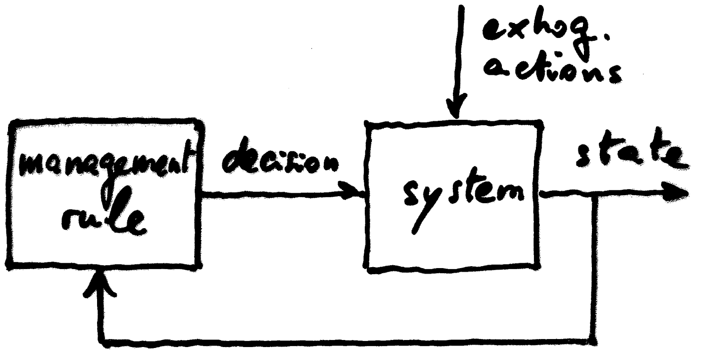
open loop control





$\Downarrow$

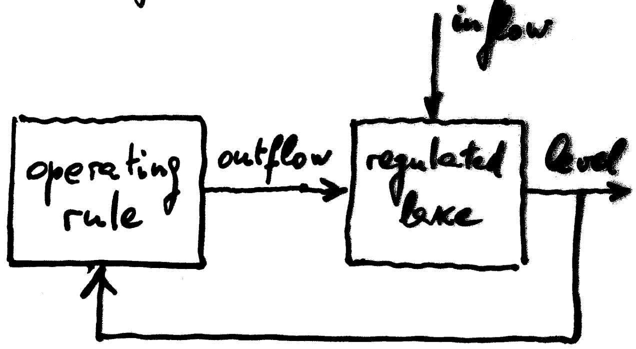
MANAGEMENT

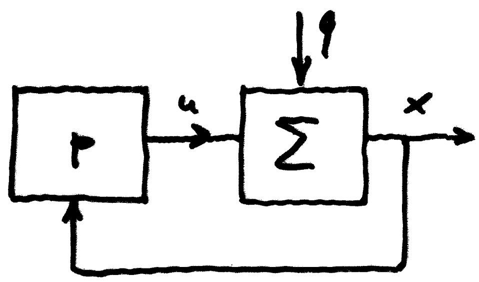


select the best management rule and use it forever

closed loop control

feedback





$\Downarrow$

$$\dot{x}(t) = f(x(t), p, q) \quad \Longleftarrow \quad \dot{x}(t) = \underbrace{g\big(x(t), u(p, x(t)), q\big)}_{f(x(t),\, p,\, q)}$$

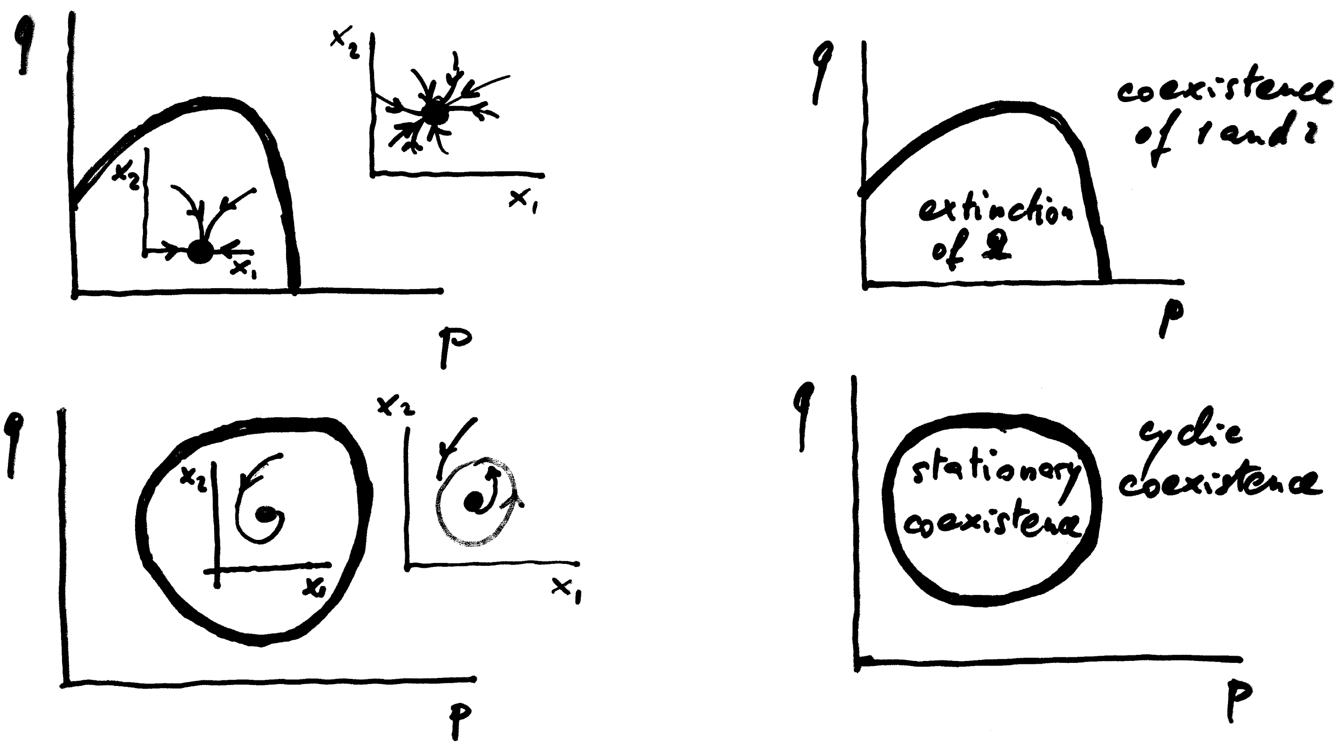
REMARKS

About the system	continuous-time finite dimensional discrete-time " " finite (automaton) infinite-dimensional probabilistic automaton CNN ⋮
About disturbances	constant known/unknown periodic $q \sin(\omega t)$ stochastic process ⋮
Constraints	on p on q on x butget constraints
Available information	on Σ on q (known, measurable, predictable, ...) adaptive control
Choice of p	from experience optimality arguments (expectation, min variance, min max, ...)

$$\dot{x} = f(x, p, q)$$

PROBLEM : what happens if p and/or q are changed ?

Small variations of p and or q can generate qualitatively important changes of the behavior of the system

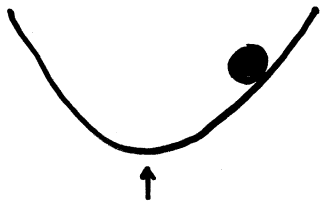


On opposite sides of the curve the asymptotic behavior of the system is qualitatively differen

These curves are called <u>bifurcation curves</u>.

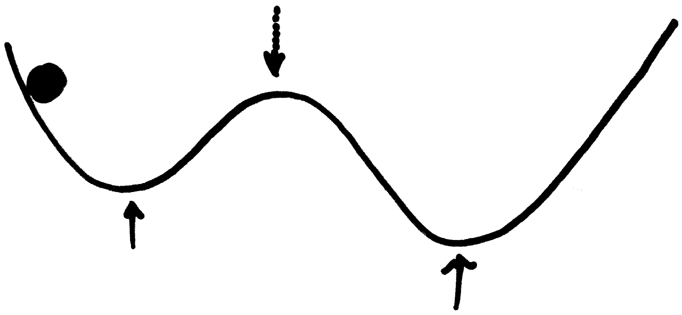
MULTIPLE ATTRACTORS AND CATASTROPHES

In the two previous examples the asymptotic behavior of the system does not depend upon initial conditions

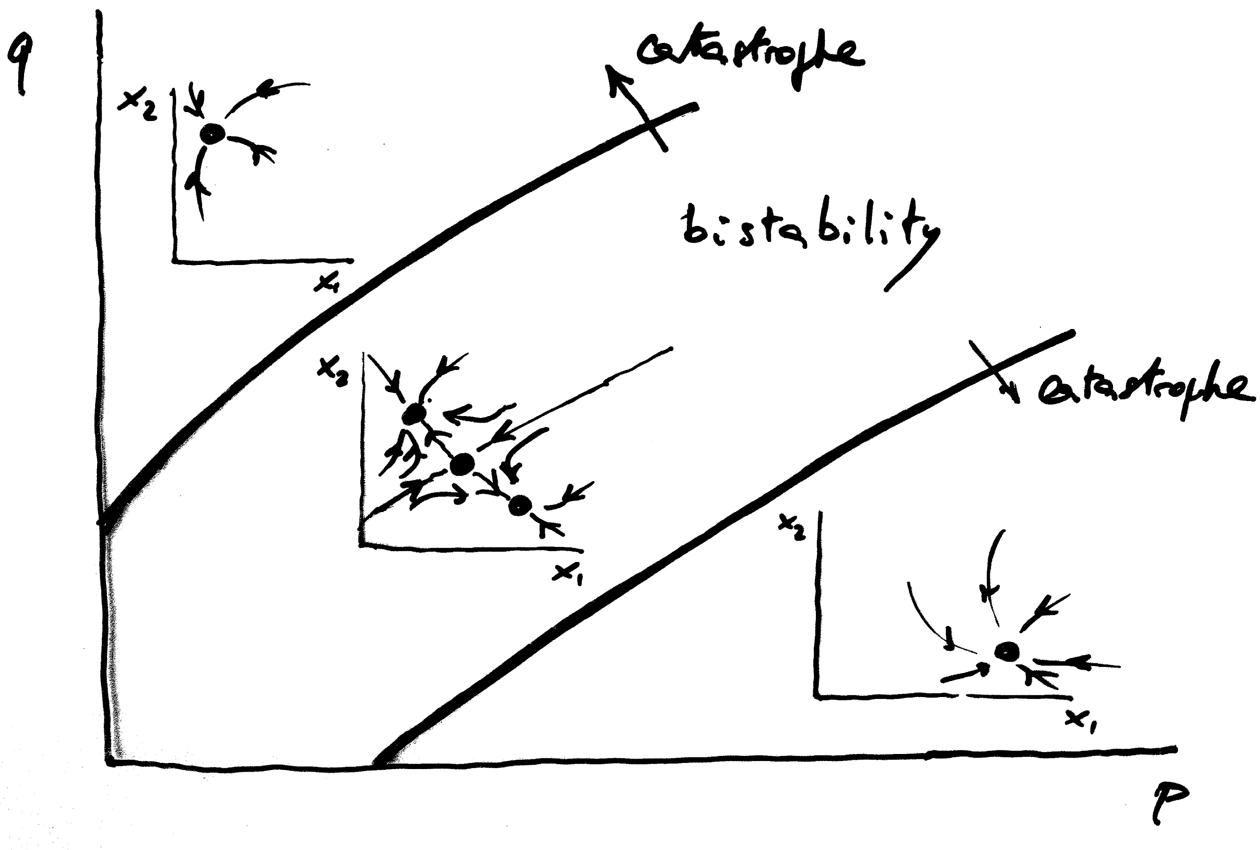


unique stable equilibria

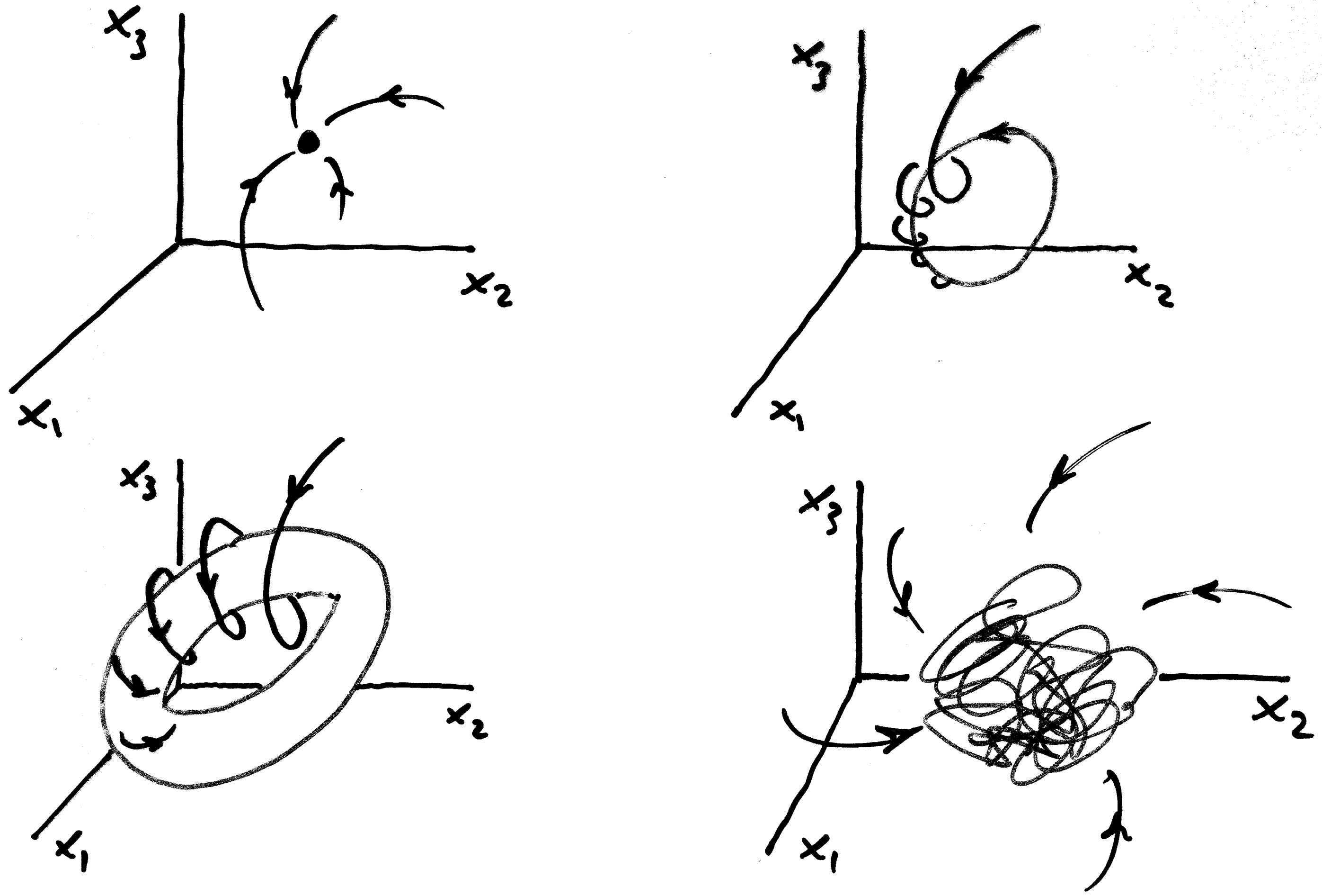
In other cases the asymptotic behavior of the system depends upon initial conditions



2 stable equilibria
1 unstable equilibrium



SIMPLE AND COMPLEX ATTRACTORS



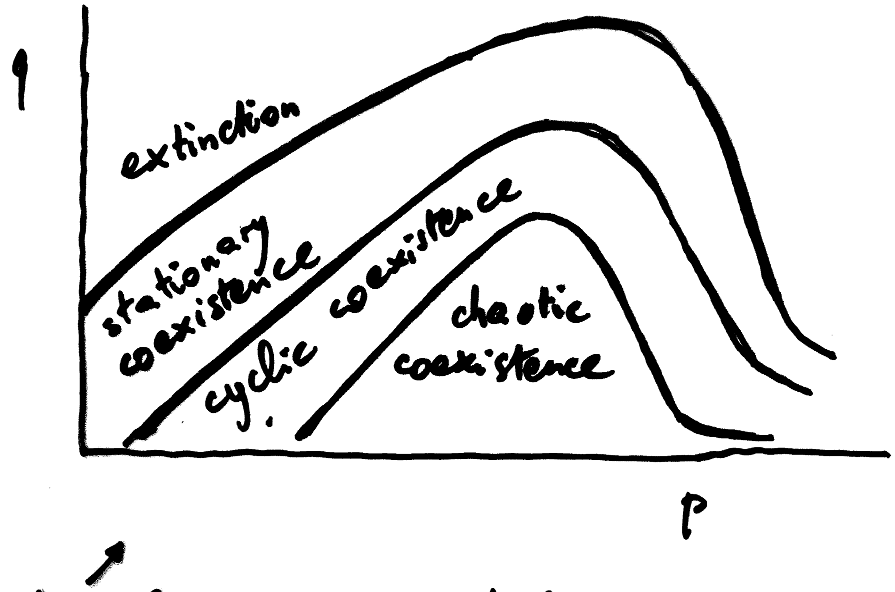
equilibrium → stationary regime

cycle → cyclic (periodic) regime

torus → quasiperiodic regime

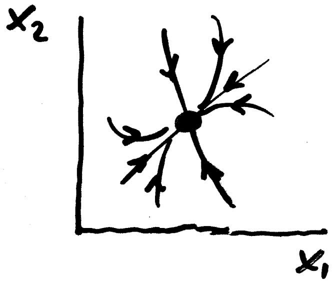
strange attractor → chaotic regime

CHANGE OF REGIME

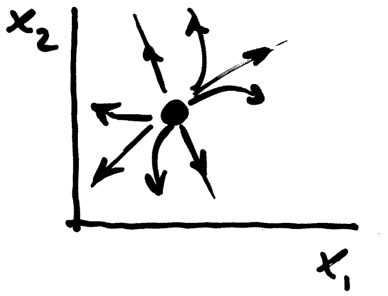


In this figure each bifurcation curve corresponds to a change of regime

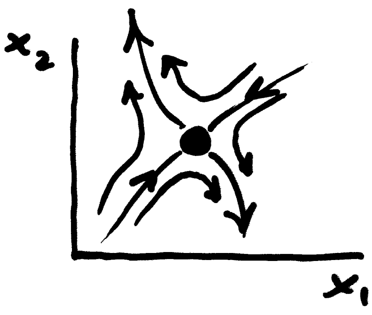
ATTRACTORS, REPELLORS AND SADDLES



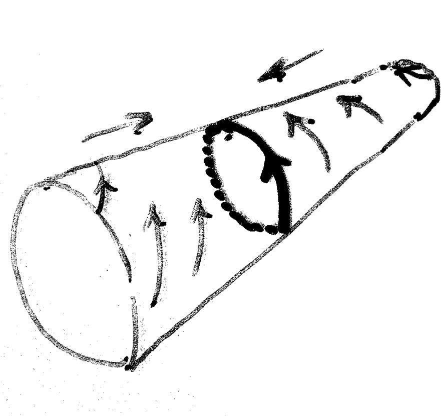
attractor

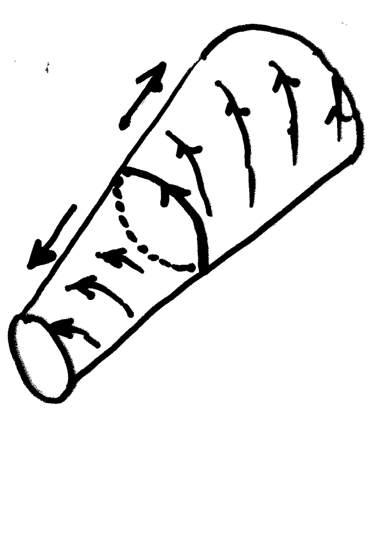


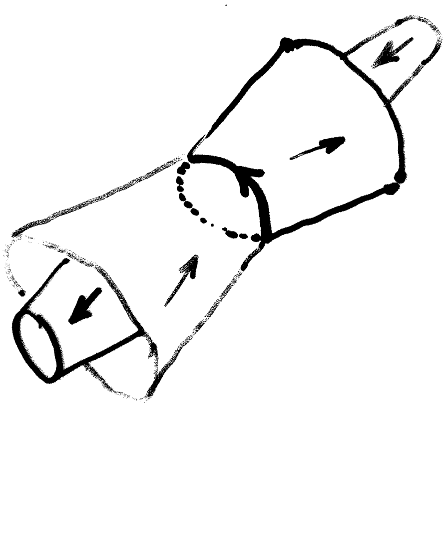
repellor

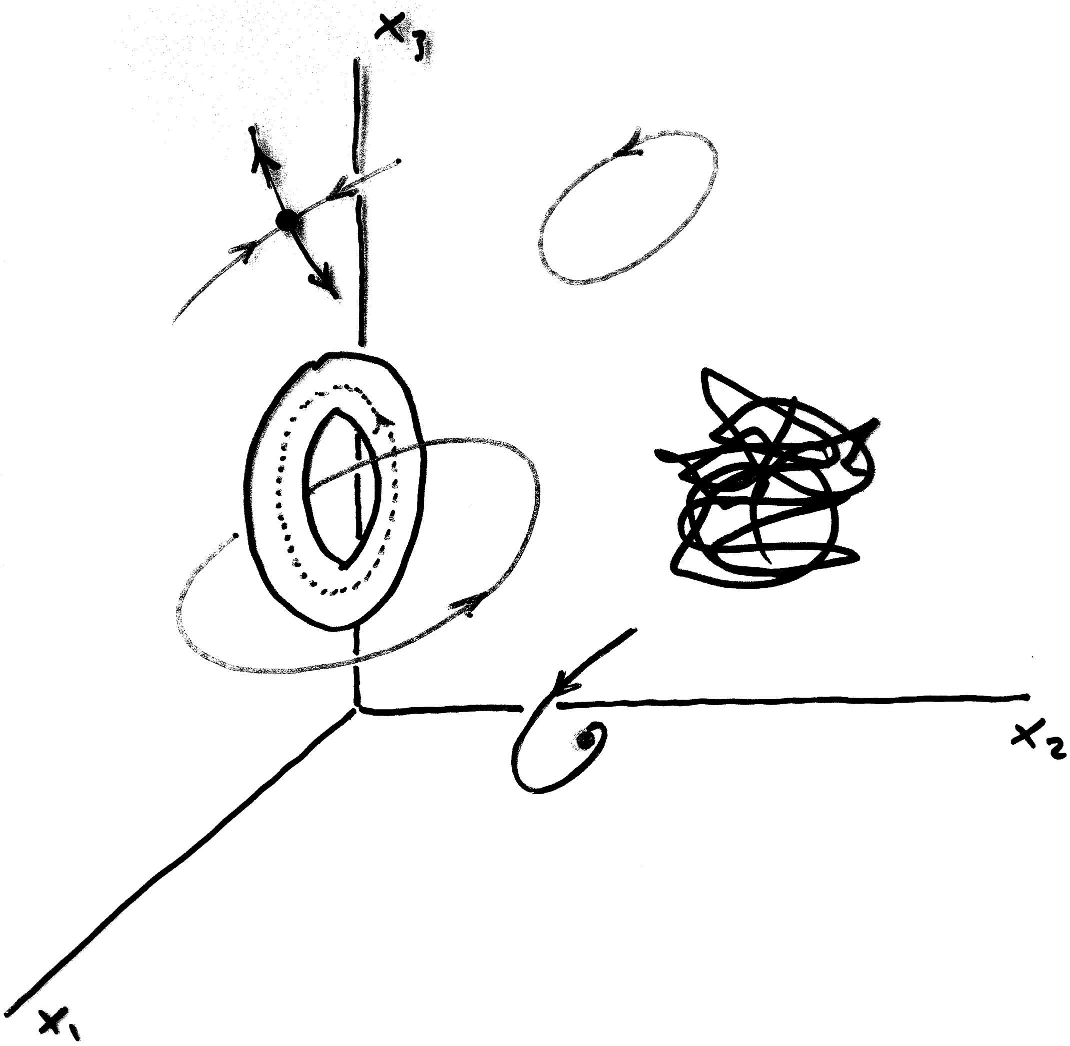


saddle









If attractors, repellors and saddles are separated for a given value (p, q) of parameters, they remain separated for a small perturbation of the parameters.

In other words, small parameter perturbations cannot give rise to qualitatively significant changes.

<u>Thus</u> : <u>bifurcations correspond to collisions of attractors, repellors and saddles</u>

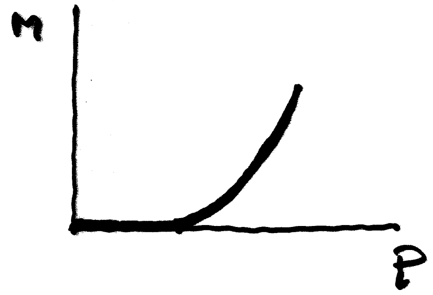
Example (Pollution control : see further reading)

R = resource
P = pollution
C = capital

$$\dot{R} = R(1-R) - M(P)R + s$$
$$\dot{P} = w\,D(C) - aP - bPR$$
$$\dot{C} = -eC + f \cdot D(C) \cdot \pi(R,P)$$

investment

perception function



excess mortality

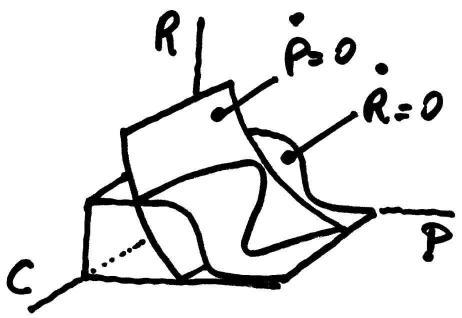
pass-through function

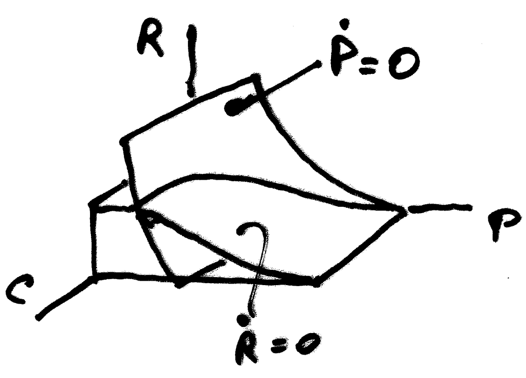
<u>Case 1</u> $\dot{C} = 0 \iff C = \text{const.} \iff$ maintain C constant

<u>Case 2</u> $\dot{C} \neq 0$ $\pi = \pi(R)$

<u>Case 3</u> $\dot{C} \neq 0$ $\pi = \pi(P)$

CASE 1





CASE 2

CASE 3

see paper