ACADEMIA ENGELBERG

2nd Dialogue on Science – 15 - 17 October 2003
in Engelberg, Switzerland

Pervasive Nanotechnology

Presentation to the lecture

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SCIENCE & TECHNOLOGY on the NANOMETER SCALE

CONTINUATION of a DEVELOPMENT

- **MINIATURIZATION**
- **MACRO- MOLECULES**

NEW NANO - TERRITORY

- **NEW POSSIBILITIES**
- **MERGE DIFFERENT DEVELOPMENTS**
- **NOVEL APPROACHES & CONCEPTS**

→ **NEW OPPORTUNITIES**

NANO is DIFFERENT

PERVASIVE:

EVERYWHERE AT ANYTIME

PENETRATING EVERYTHING EVERYWHERE

PERVASIVE COMPUTING

WAS ENABLED BY

PERVASIVE ELECTRONICS

AND

PERVASIVE COMMUNICATION

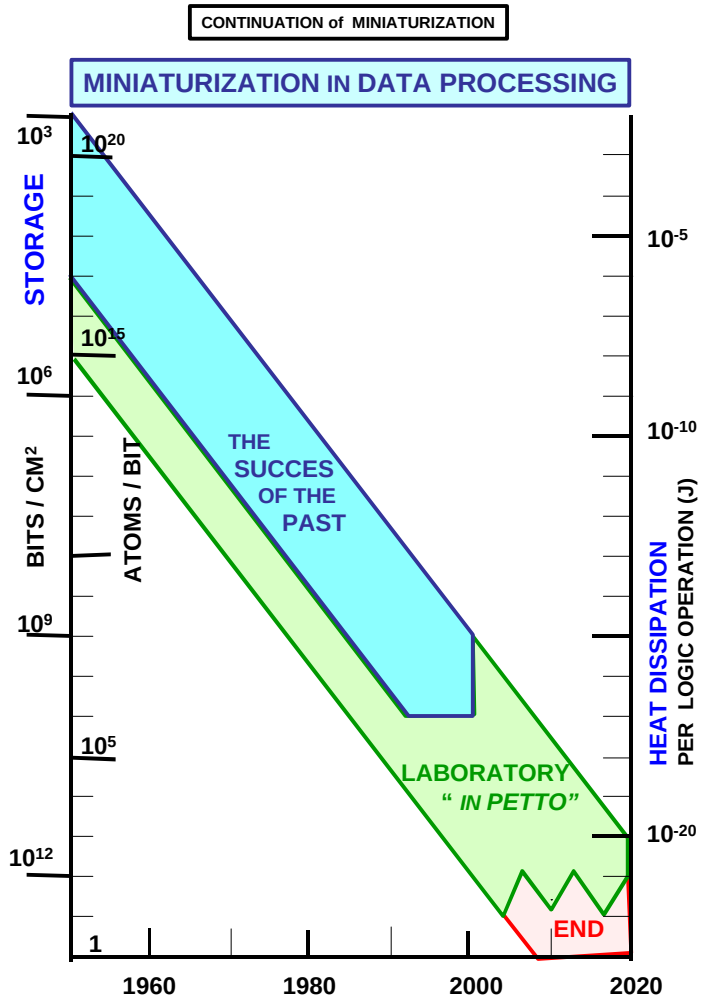
PERVASIVE REQUIRES
SMALL AND INEXPENSIVE

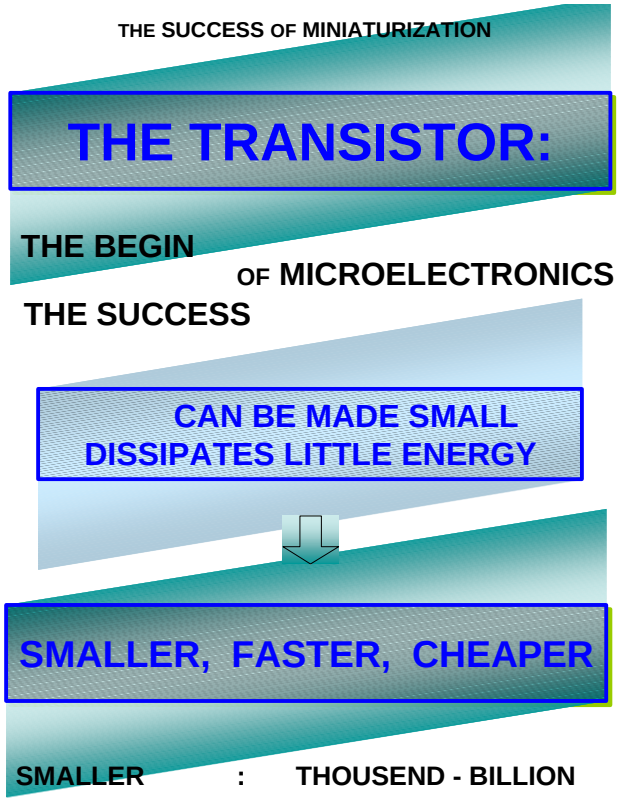
MINIATURIZATION OF ELECTRONICS
REDUCED

• SIZE	BY	10^4 - 10^{12}
• PRIZE		10^4 - 10^7
• ENERGY CONSUMPTION		10^6 - 10^{12}
• TIMES		10^5 - 10^{10}

THE SUCCESS OF THE PAST
WAS SCALABILITY

" SMALLER, FASTER, CHEAPER "


CONTINUATION of MINIATURIZATION
MINIATURIZATION IN DATA PROCESSING
STORAGE
BITS / CM²
ATOMS / BIT
HEAT DISSIPATION
PER LOGIC OPERATION (J)
10³
10²⁰
10¹⁵
10⁶
10⁹
10⁵
10¹²
1
10⁻⁵
10⁻¹⁰
10⁻²⁰
THE
SUCCES
OF THE
PAST
LABORATORY
" IN PETTO"
END
1960
1980
2000
2020


THE SUCCESS OF MINIATURIZATION
THE TRANSISTOR:
THE BEGIN
OF MICROELECTRONICS
THE SUCCESS
CAN BE MADE SMALL
DISSIPATES LITTLE ENERGY
SMALLER, FASTER, CHEAPER
SMALLER : THOUSEND - BILLION
FASTER : THOUSEND - BILLION
CHEAPER : MILLION
LESS ENERGY : TRILLION

THE SUCCESS OF MINIATURIZATION

1 TRILLION x LESS ENERGY PER CALCULATION

NEVERTHELESS, THE ENERGY COSTS OF OF DATA PROCESSING AMOUNT TO

1 TRILLION USD / YEAR

HUMAN: 80 USD / YEAR

AND **CAN THINK**

FOR **8 USD / YEAR**

THE SUCCESS OF MINIATURIZATION

SMALL → PERVASIVE

MICROELECTRONICS:

HEARING AID
CELLULAR PHONE
GPD
PC
MAIN FRAME
JUMBO
SATTELITES

YEARLY PRODUCTION OF TRANSISTORS:

1’000’000’000’000’000’000

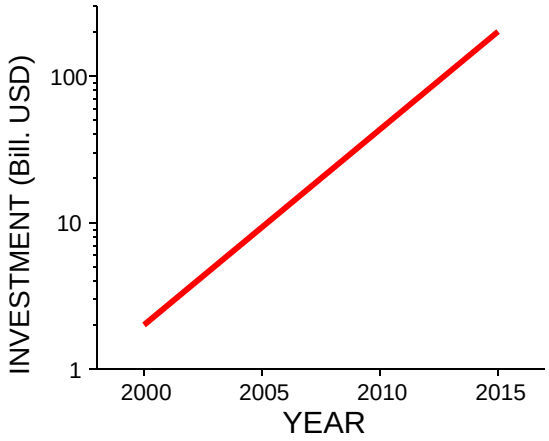
WITH RADIO TUBES OF 1960

WE WOULD STAND KNEE-HIGH IN THEM

CONTINUATION of MINIATURIZATION

SMALL IS NOT ALWAYS CHEAP

PROJECTED INVESTMENT FOR MICRO FABRICATION NFACILITY



NANO FABRICATION FACILITY

?

THE NEW NANO - TERRITORY

MICROELECTRONICS

PERFORMS

- DATA PROCESSING AND
- DATA TRANSMISSION

NANO TECHNOLOGY

SMART SENSORS
CREATE , PROCESS & TRANSMIT DATA

SMART ACTUATORS
CONTROL & EXECUTE ACTION

INTEGRATED PROCESSOR SYSTEMS
INCLUDE SENSING AND ACTUATION FOR "*in situ*" PROCESSING

ULTIMATE GOAL OF SCI. & TECH. ON THE nm SCALE

PERFORM

ELECTRICAL,
MECHANICAL,
CHEMICAL,
THERMAL, ...

} ⟷ {

SENSING
PROCESSING
ACTUATION

WITH

SYSTEMS WORKING ON THE NANOMETER SCALE

BUILD PERVASIVE BRIDGES

BETWEEN

VIRTUAL WORLD OF PROCESSING **AND** **REAL WORLD OF ACTION**

ULTIMATE TECHNICAL REQUIREMENT

ADDRESS, MEASURE, CONTROL
STRUCTURE, and MODIFY
on the NANOMETER SCALE

PROPERTIES
STRUCTURES
COMPONENTS
FUNCTIONS
PROCESSES

including

THEIR SYNTHESIS to SYSTEMS of
MICRO and MACRO DIMENSIONS

and

PREPARATION of APPROPRIATE
MATERIALS

- **NOVEL PROPERTIES & FUNCTIONS**
  From CONDENSED MATTER BEHAVIOR
  to ATOMIC and MOLECULAR PROPERTIES
  NEAR FIELD, BALLLISTIC, COUNTING

- **FAST**
  MECHANICS, “CHEMICS”, AND “THERMICS”

- **SENSITIVITY**
  ATOMIC and MOLECULAR LEVEL

- **PERVASIVE BEYOND ELECTRONICS**
  ELECTRICAL, MECHANICAL, and CHEMICAL
  SENSING, PROCESSING, and ACTUATION

- **DISCIPLINS MERGE**
  COMMON NANO SCALE

- **NOVEL STRATEGIES**
  NATURE’S WAY, COUNTING, DISCRETE

THE NEW NANO - TERRITORY

SPEED and SENSITIVITY

are KEY INGREDIENTS of a

NEW, POWERFUL, and PERVASIVE

NANO - MECHANICS
- CHEMISTRY
-THERMODYNAMICS

For

INTEGRATED
- SENSING
- PROCESSING
- ACTUATION

THE NEW NANO - TERRITORY

NANO - MECHANICS

MECHANICS UNDERSTOOD AS MOTION OF ATOMIC CORES (MASS) AND DEFORMATION OF THEIR ARRANGEMENT

- FAST Mhz - Ghz, µsec - psec
  → **MECHANICS COMPLEMENTS ELECTRONICS**
- SENSITIVE STIFFNESS ∝ d
  ?m ∝ d^4
- EXTREM DEFORMATIONS
  - $\sigma_{yield} >> \sigma_{yield, bulk}$ (COLLECTIVE SLIP)
  - $R_{curv} \propto d$
  - "REVERSIBLE" MASS TRANSPORT

  → **MICRO- & MACRO MOTION SYNTHESIZED FROM DEFORMATION & MASS TRANSPORT**
- LOW ENERGY
  ELASTIC ENERGY IN THE kT RANGE
  → **"BEAT" kT**
- VARIETY OF BASIC FUNCTIONALITY
  → **HIGH SENSITIVITY, INTERGRATED SENSOR-PROCESSOR-ACTUATOR SYSTEMS**

THE NEW NANO - TERRITORY

FAST

- MOTION

  n^2 μ **STIFFNESS / MASS** μ $\mathbf{d^{-2}}$

  n μ **VELOCITY / d**

d:	10cm	10µm	10nm
ν:	400Hz	4MHz	4GHz

- DIFFUSION

  t_{DIFF} μ $\mathbf{<d^2>/D_{DIFF}}$

Volume:	1L	1000µm³	1000nm³
τ_{DIFF}:	1Day	1msec	1nsec

- THERMAL RELAXATION

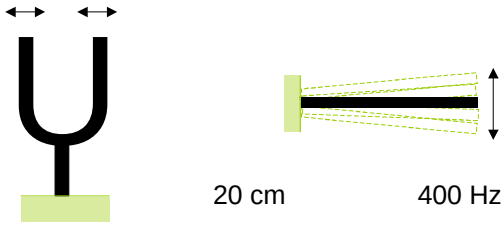
  t_{TH} μ $\mathbf{Q/\dot{Q}}$ μ **d**

  nm → nsec

THE NEW NANO - TERRITORY

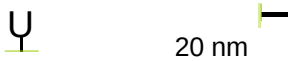
SMALLER - FASTER

MECHANICS: n μ 1/d



20 cm 400 Hz

20 µm 4 Mhz

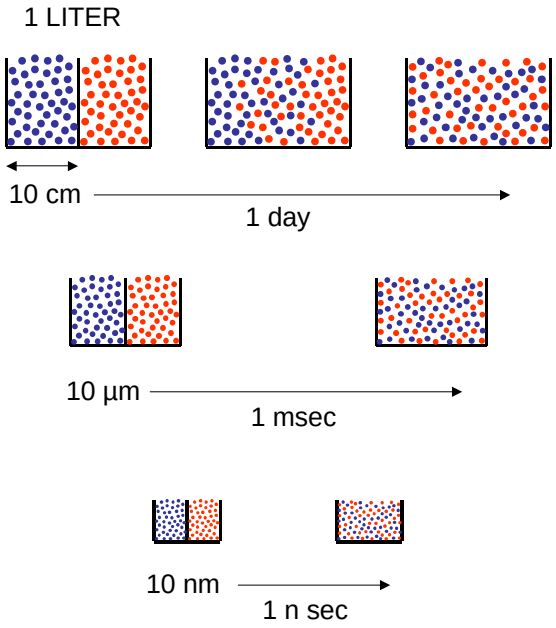


20 nm 4 Ghz

THE NEW NANO - TERRITORY

SMALLER - FASTER

DIFFUSION: $t_{DIFF} \mu d^2$



THE NEW NANO - TERRITORY

SENSITIVITY

RECOGNIZE, CONTROL, MODIFY
SMALL BY SMALL
WEAK BY WEAK

- **LOCAL PROBE METHODS**
  ONE OR A FEW ATOMS INTERACT WITH ONE OTHER OR FEW OTHER ATOMS

- **MOLECULAR RECOGNITION**
  MOLECULE RECOGNIZES MOLECULE

- **MECHANICS**
  STIFFNESS $\propto d$
  MICROBALANCE: $\Delta m \propto m \bullet \Delta\omega/\omega$
  $\propto d^4$ or d^3

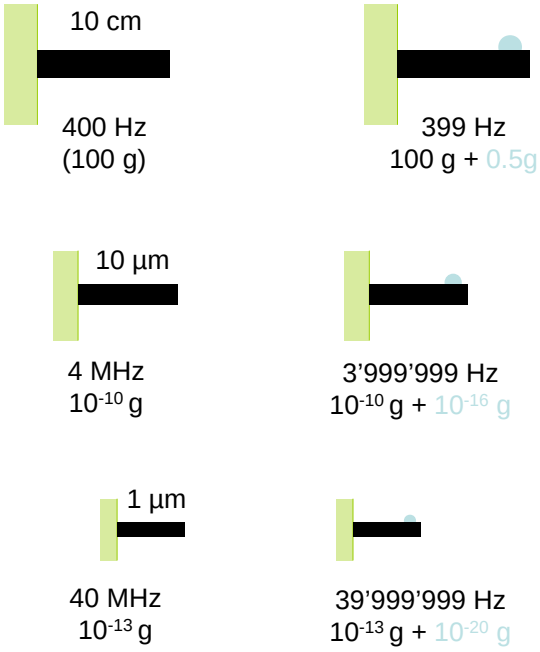
- **DISCRETE PROPERTIES**
  e.g. ENERGY LEVELS
  → "DISCRETIZING"

THE NEW NANO - TERRITORY

MORE SENSITIVE

$\Delta m = -2\ m \bullet \Delta\omega/\omega$

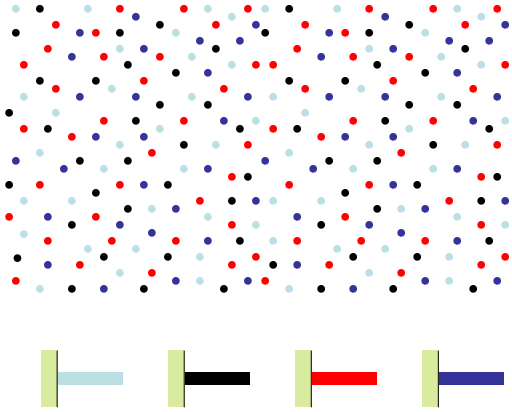
$m \propto d^4$ or d^3 $\qquad \Delta\omega = 1$ Hz



THE NEW NANO - TERRITORY

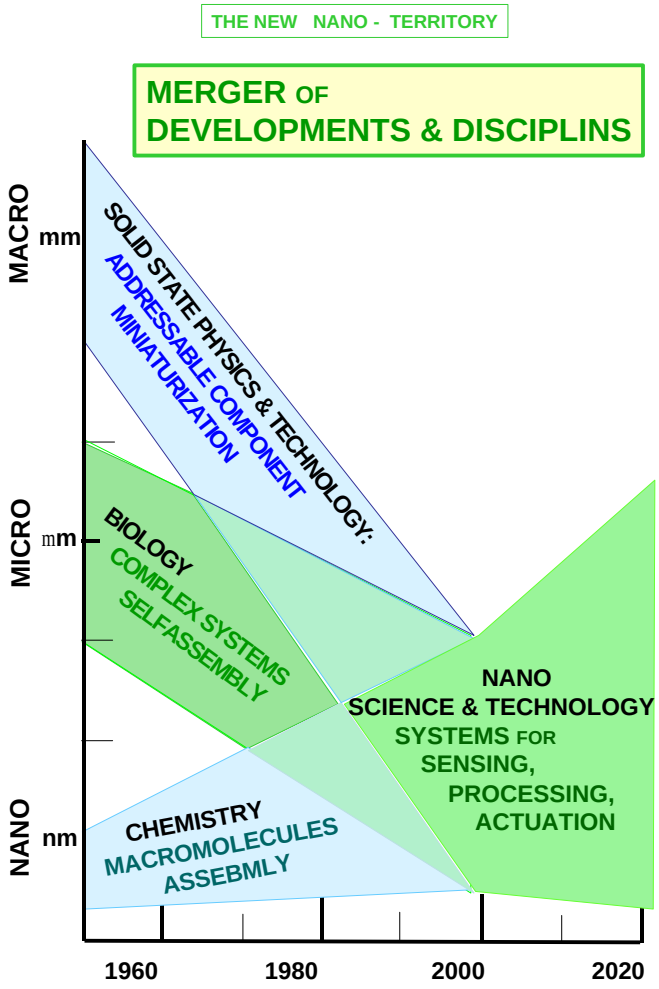
MORE SENSITIVE

- **STRATEGY OF "DISCRETIZING"**



EACH CANTILEVER -SENSOR ACCEPTS ONE SPECIES ONLY

KEY:
FUNCTIONALIZATION of the CANTILEVERS


THE NEW NANO - TERRITORY
MERGER OF
DEVELOPMENTS & DISCIPLINS
MACRO
mm
MICRO
mm
NANO
nm
SOLID STATE PHYSICS & TECHNOLOGY:
ADDRESSABLE COMPONENT
MINIATURIZATION
BIOLOGY
COMPLEX SYSTEMS
SELFASSEMBLY
CHEMISTRY
MACROMOLECULES
ASSEBMLY
NANO
SCIENCE & TECHNOLOGY
SYSTEMS FOR
SENSING,
PROCESSING,
ACTUATION
1960
1980
2000
2020

THE NEW NANO - TERRITORY

SOLID STATE TECHNOLOGY
WITH MINIATURIZATION
BRINGS THE CONCEPT OF
ADRESSABILITY

NANO OBJECTS AND COMPONENTS
BECOME INDIVIDUALS

(MACROMOLECULAR) CHEMISTRY
BRINGS THE CONCEPT OF
ASSEMBLY OF
NANO OBJECTS & COMPONENTS

BIOLOGY
BRINGS THE CONCEPTS OF
SELFASSEBLING & WORKING
WITH COMPLEX SYSTEMS

THE NEW NANO - TERRITORY

THE GRAND CHALLENGES

LOCAL GROWTH

NANO SCALE MATERIAL SCIENCE

NANO- INTERFACE

INVASIV,
INTERFACE **AND** CONNECTION NODES
AS ACTIVE COMPONENT

NOVEL COMPONENTS & FUNCTIONS

MECHANICAL, CHEMICAL, THERMAL...

ENERGY and INFORMATION TRANSFER

LOCAL CHEMICAL ENERGY
FIELDS

THEORY

COMPUTATIONAL SCIENCES

NANOSCALE MATERIAL SCIENCE

NANO STRUCTURED MATERIALS
NOVEL PROPERTIES AND FUNCTIONS:

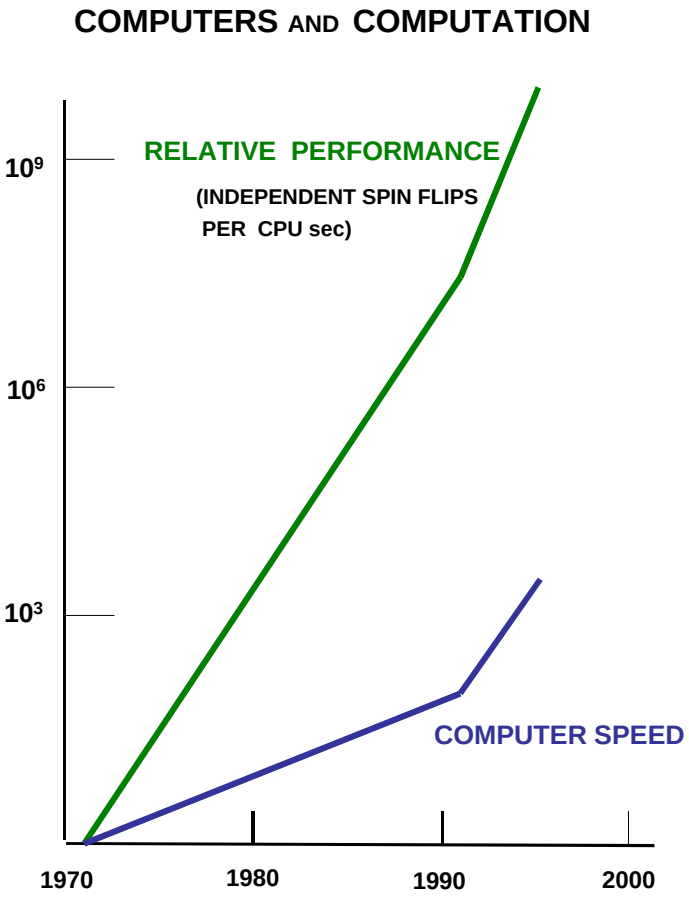
- **BULK**
  FROM STEEL TO POLYMER TO NANO COMPOSITS
- **SURFACE**
  SELFASSEMBLIES
- **NANO PARTICLES** HEALTH RISK
  COLLOIDS, AEROSOLS, CLUSTERS,
  MAGN.-COLUMNS, Q-DOTS, C-NANOTUBES

NANO STRUCTURING MATERIALS

- NANOSTRUCTURING BEYOND SILICON
- LOCAL NANOSTRUCTURES
  COMPONENTS, CONTACTS, CONNECTORS
  CONSTRICTIONS Q-WELLS-WIRES-DOTS,

LOCAL NANO - FABRICATION

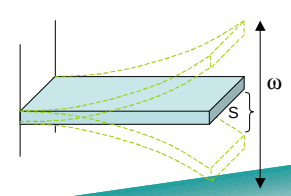
- MANIPULATION
- SELFASSEMBLY OF NANO PATTERNS
- LOCAL GROWTH


COMPUTERS AND COMPUTATION
RELATIVE PERFORMANCE
(INDEPENDENT SPIN FLIPS
PER CPU sec)
10⁹
10⁶
10³
COMPUTER SPEED
1970
1980
1990
2000

THE NEW NANO - TERRITORY

MECHANICAL COMPONENTS

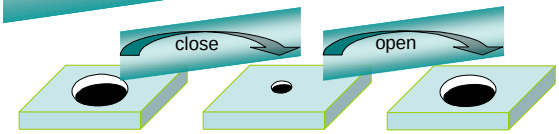
- CANTILEVER OR SIMILAR



- **EXCURSION S**
  - FORCE
  - STRAIN
- **FREQUENCY ω**
  - $\Delta\omega_f$: FORCE GRADIENT
  - Γ: DISSIPATION

KEY CHALLENGE:
FUNCTIONALIZATION OF CANTILEVER

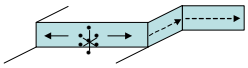
- ADJUSTABLE HOLES



- SWITCH
- GATE
- SIEVE

COUNTING

- GUIDES (RAILS, TUBES)



CONTROLLED TRANSPORT