Research activities of Inria
Environment, sustainable development & energy

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Outline

- **Overview of research activities**
  - ★ Many contributions
  - ★ Strong growth
  - ★ Few highlights
- **Strategy**
  - ★ Sustainable development implies profound changes
  - ★ Research & « all activities »
  - ★ Organization / incentive actions
  - ★ Available means
  - ★ Lean ICT

A cartography of Inria contributions (by Peter Sturm - 2019) +84 project-teams implied

- Carbon footprint reduction of ICT
  - ✓Reduction of energy consumption
  - ✓Better usage, recyclability
  - ✓Optimizing technologies
- Understanding/modeling environment
  - ✓Ocean, atmosphere, climate, weather
  - ✓Ecology, ecosystems, biodiversity
  - ✓Decontamination
- « Smart » mobility/cities/agriculture
- Energy : production/distribution/storage
  - ✓Renewable energies, nuclear fusion/fission
  - ✓Consumption patterns/monitoring
- …

Carbon footprint reduction of ICT

- measuring and analyzing energy consumption of various computing architectures, AVALON
- increase energy efficiency of computing architectures, AVALON
- reducing energy consumption of internet service provider networks, COATI
- compiling to reduce energy consumption of applications, CORSE
- prediction of the energy consumption of a chip, EVA
- low-power Internet of Things, INFINE
- performance analysis of a data center by renewable energy ressources, NEO
- zero Power Computing Systems, PACAP, SOCRATE
- energy proportional networks, PANAMA
- clouds, distributed systems
  - optimizing energy management in distributed clouds, MYRIADS
  - energy cost models for heterogeneous cloud infrastructures and for energy distribution grids, MYRIADS
  - exploiting renewable energy in clouds, MYRIADS
- energy-aware algorithms and scheduling strategies, ROMA
- measuring and optimizing the energy footprint of ICT software infrastructures, SPIRALS
- IoT, sensor networks
  - improving energy efficiency for wireless sensor networks and distributed computing, CAIRN
  - energy-efficient mechanisms in low-power wireless networks, EVA
  - energy-aware routing for IoT for smart grids, FUN
- HPC, supercomputing
  - improving energy efficiency of HPC, CAMUS, CTRL-A, DATAMOVE
  - energy-efficient heterogeneous supercomputing architectures, PACAP
  - energy-efficient HPC and data storage, KERDATA
- Better usage of materials, including recyclability/ reparability by design, less dispersive usage of materials
  - nothing (for the moment)

Lean ICT

Taking into account energy consumption in the design of new algorithms, architectures & langages:

- High-performance and energy-efficient neural networks
- Learning memory and energy efficient dictionaries

TOTH, PANAMA, ROMA, ALPINES

- HPC: fast and stable numerical schemes, high order ?
- Deep neural network & numerical analysis
- Compiler optimizations
- Parallelization
- Micro-architectural features
- GPU, many-cores, FPGA

CASH, CORSE, PACAP

- Also energy efficient embedded systems

SPADES, CAIRN

Carbon footprint reduction (other techno.)

- Optimizing technologies to lower energy consumption
  - ✳ Vehicles
    - ✓ modeling and optimization for active flow control technologies to improve aerodynamic performance of cars, ACUMES
    - ✓ experimental fluid mechanics to limit aircraft fuel consumption, FLUMINANCE
    - ✓ optimizing aircraft trajectories for reduction of fuel consumption, COMMANDS
  - ✳ Buildings, cities
    - ✓ tools for assessing thermal performance of buildings, I4S
    - ✓ resource consumption analysis for optimizing energy consumption in industrial factories, LACODAM
    - ✓ optimization for building design (including reduction of environmental impact), ACUMES
- Better usage of materials, including recyclability/reparability by design, modularity, less dispersive usage of materials
  - ✳ Sustainable use of resources in construction, SERENA

« Smart » mobility

- modeling and control of road traffic, among which control of autonomous vehicles, ACUMES
- networking for mobility: dynamic car-pooling combined with multi-modal transportation systems, COATI
- modeling of road traffic (traffic jams), COFFEE, ACUMES, RITS
- computing optimal multi-modal itineraries in cities, including car pools, GANG
- road traffic modeling for energy management of hybrid vehicles (with IFPEN), COMMANDS
- dynamical distribution of network control to enable message dissemination in Intelligent Transport Systems, DIANA
- energy trade-offs for end-to-end communications in urban vehicular networks, DYOGENE
- machine learning and data mining to study traffic congestion, parking, ride-sharing, pollution and energy consumption, MAGNET
- ad hoc networks for (autonomous) vehicles, EVA, FUN
- vehicle routing, INOCS
- traffic control, NECS
- optimization for electric car-sharing systems, INOCS
- IoT for connected vehicles, KAIROS
- calibration of sensors for autonomous cars, MISTIS
- validation of safety properties for automated transport systems, MEXICO
- critical infrastructure operation, such as public transportation systems and power distribution networks, ILDA
- autonomous vehicles, RAPSODI
- car sharing, RAPSODI
- autonomous car control and path planning, SEQUEL
- validating the safety of autonomous vehicles, TAU
- integrated models for transportation and land use, STEEP

« Smart » cities/agriculture

- Cities and homes
  - wireless networks for smart cities, e.g. for environmental monitoring (such as atmospheric pollution), AGORA
  - data assimilation for atmospheric and noise pollution monitoring in cities, ANGE
  - sensing for smart cities, FUN
  - air quality monitoring in large and dense urban areas, ILDA
  - energy efficient smart homes, PERVASIVE
  - energy management and saving solutions for smart homes, SPIRALS
  - modeling urban sprawl, STEEP
- Agriculture and food production
  - modeling agrifood chains, i.e. the chain of all processes leading from the plants to the final products, including waste treatment, GRAPHIK
  - decision support systems for agronomy using ontologies and structured knowledge to integrate scientific data coming from different sources, GRAPHIK
  - cattle monitoring from multiple sensors placed on calves for the early detection of diseases, LACODAM
  - IoT and data analysis to improve farming conditions, LACODAM
  - tools to increase the durability of the wheat supply chain, GRAPHIK
  - characterization and simulation of agricultural landscapes, ORPAILLEUR
  - formal concept analysis for the representation of farmer experience, ORPAILLEUR

Consumption in networks

COATI, RESIST, MADYNE, MYRIADS

- Fault detection & adaptation
- Routing in Software Defined Networks: 5 to 35% savings on networks of Internet Service Providers (soft: Graph & Sagemath)
- What is the economy by exploiting the fact that users are ready for service degradation?
- IT & constraints (heterogeneity, default, crisis…)
  - self-organization Future Ubiquitous Network
  - taking into account an assortment of networks (wifi, ad-hoc, cellular, bluetooth)
  - smart cities
  - survivors alternately broadcast alert messages

AGORA, FUN, SOCRATE, SUMO

Energy : production/distribution/storage

- Renewable energy
  - sensitivity analysis for simulating floating offshore wind turbines, AIRSEA
  - simulation of hydrodynamics (of rivers, lakes, etc.), application to micro-algae production (e.g. for biofuel), ANGE
  - modeling and optimization for hydro-energy, ANGE, CARDAMOM, LEMON
  - control for the production of methane and/or biohydrogen from organic wastes, BIOCORE
  - modeling and optimizing micro-algae production (e.g. for biofuels), ANGE, BIOCORE
  - applications of HPC in simulations for energy production (wind, hydro, biomass, etc.), CORSE
  - control for Wind Farm Power Maximization, DISCO
  - uncertainty modeling for wind turbine control, MULTISPEECH
  - monitoring system for wind turbines, I4S
  - numerical modeling for wind and hydro-energy, MEMPHIS
  - stochastic models for solar power (irradiance prediction), NEO
  - HPC and simulation for energy production (renewable as well as oil and gas), HIEPACS
  - decentralized, local, production (and consumption) based on intermittent renewable sources, PERVASIVE
- Nuclear
  - heat transfer and other fluid dynamics modeling for nuclear power plant design and operation, CAGIRE
  - multi-physics simulation to study building materials for nuclear reactors, HIEPACS
  - industrial risks in energy production (fission), SERENA
  - simulation for nuclear fusion, CASTOR, HIEPACS, TONUS
  - fluid mechanics for nuclear fusion, COFFEE
  - Waste
    - ✓ numerical modeling of multiphase porous media flows for simulation of nuclear waste repositories (collaboration with Andra), COFFEE
    - ✓ parameter identification to characterize sites destined for nuclear waste, DEFI
    - ✓ modeling geological disposal of radioactive wastes, FLUMINANCE
    - ✓ algebraic and geometric domain decomposition for subsurface/groundwater flows, with application to radioactive waste deep geological disposal, HIEPACS
    - ✓ nuclear waste disposal in deep underground repositories, SERENA

Optimization/design of wind turbines

- Collaboration with VALOREM
  - Optimization of blades for wind turbines
  - Coupled simulations
    - ★ fluid: 3d Navier-Stokes (LES)
    - ★ structure: BEM model
  - Assembly of a mast of wind measurements, deformation and pressure sensors on a blade

MEMPHIS

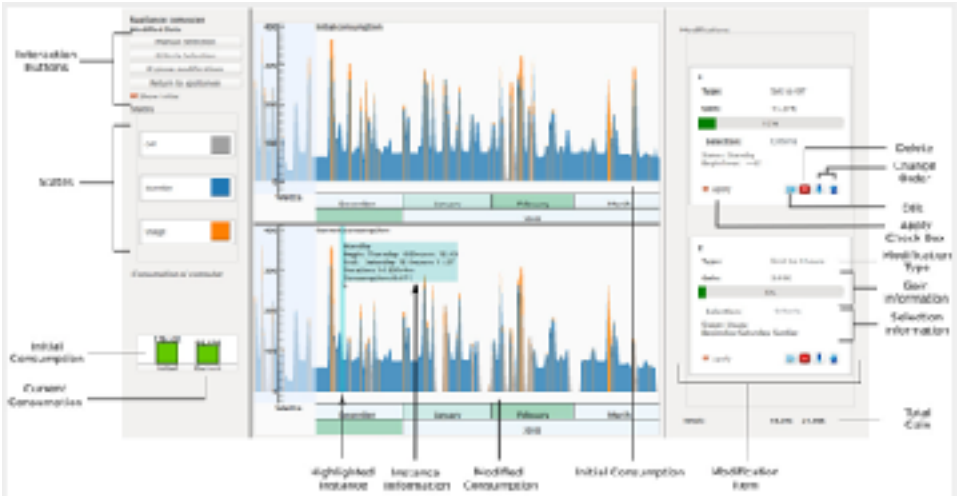
Inria

Energy : distribution/storage/consumption patterns

- optimization and control problems in energy networks, DISCO
- modeling and control of district heating networks, DISCO
- distributed control of a fleet of batteries, DYOGENE
- distributed control design for balancing the grid using flexible loads (intermittent energy sources), DYOGENE
- wireless networks for power plants, EVA
- pricing models for energy demand side management, smart grids, INOCS
- optimization problems arising in the management of gas networks, INOCS
- pattern mining for detection of energy consumption patterns, LACODAM
- energy cost models for heterogeneous cloud infrastructures and for energy distribution grids, MYRIADS
- critical infrastructure operation, such as public transportation systems and power distribution networks, ILDA
- user centric energy management system, PERVASIVE
- modeling long-term investments in power systems, TAU
- simulation, calibration, and optimization of regional or urban power grids, TAU
- prediction of the power flow on the entire French territory over several years, TAU
- smartgrids : POLARIS, EASE, HYCOMES, MYRIADS, COMMANDS, INFINE, TROPICAL

Consumption in a domestic environment

- **Activelec:** visualization tool for non-expert users



MAVERICK

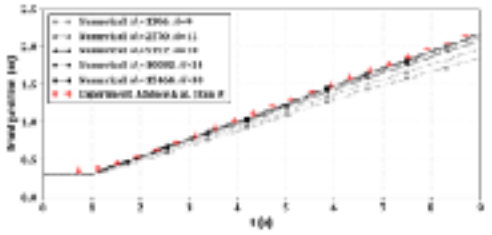
- "eco-feedback": what happens if... ?
  - I turn off the devices instead of leaving them on standby
  - I change the program of the washing machine
  - (data-driven) sociological models

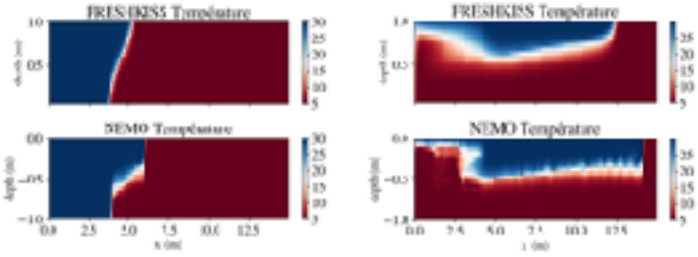
Understanding/modeling environment

- Ocean, atmosphere, climate, weather
  - modeling for oceanic and atmospheric flows (including data assimilation, HPC, uncertainty quantification etc.), AIRSEA
  - modeling of geophysical flows, for oceanography, meteorology, sediment transport modeling (estimation of sustainability of infrastructure such as canals, bridges, etc.), ANGE
  - modeling for hydrological disasters (floods, tsunamis), ANGE, CARDAMOM
  - application to computing for climatology, AVALON
  - modeling carbon fluxes between ocean and atmosphere, BIOCORE
  - data assimilation with applications in climatology, ECUADOR
  - applications of computing platforms in climate modeling, MYRIADS
  - remote sensing for meteorology, climatology, oceanography, flood modeling, FLUMINANCE, GEOSTAT
  - simulation for atmospheric chemistry, HIEPACS
  - modeling of high-impact weather events, MISTIS
  - multi-scale ocean modeling, LEMON
- Ecology, ecosystems, biodiversity
  - satellite data processing in ecology and landscape mapping, MISTIS
  - modeling of ecosystems and anthropogenic pressures, LACODAM
  - study of biological systems and social systems facing shortage of resources, DATASPHERE
  - bioinfo tools for DNA-based (meta-genomic) identification of marine biodiversity (planktonic and others) present in a sample, GENSCALE
  - modeling the propagation of invasive species, STEEP
  - semantic web for biodiversity, WIMMICS
  - crowdsource solution for assessing biodiversity etc. (PI@ntNet), ZENITH

Sea Uncertainty Representation and Forecast

- DEFI « SURF »
  - ✳ AIRSEA, ANGE, CARDAMOM, FLUMINANCE, LEMON
- Oceanography & GCM
- Accurate & stable large scale simulations
- Importance of strong mathematical stability properties
  - ✳ Wroniszewski *et al.* Benchmarking of Navier-Stokes codes for free surface simulations by means of a solitary wave, Coastal Eng., 91:1-17,2014
- Key point
  - ✳ $\Delta t, \Delta x \to 0$ or "finite" $\Delta t, \Delta x$



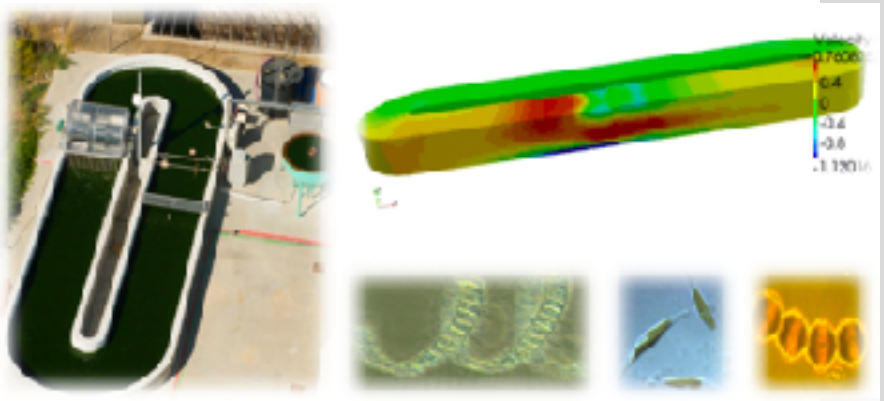


Other contributions

- Benchmarking national CO2 emission pathways, STEEP
- Links between social and natural systems
  - ✳ study of biological systems and social systems facing shortage of resources, DATASPHERE
  - ✳ study of interdependencies of natural ecosystems and socio-economic systems, and the role of digital systems on measuring and controlling the global natural/social system, DATASPHERE
  - ✳ modeling of ecosystems and anthropogenic pressures, LACODAM
  - ✳ tools to increase the durability of the wheat supply chain, GRAPHIK
  - ✳ modeling of territorial supply chains and ecological accounting for sectorial pressure assessment (e.g. on water), STEEP
  - ✳ assessing resilience of territories against interruptions of supply chains, climate change, etc., STEEP
- Decontamination
  - ✳ bacteria-based biological depollution, BIOCORE, ANGE
  - ✳ subsurface decontamination after chemical leakage, SERENA
- Environmental monitoring
  - ✳ environmental monitoring (fire detection, snow melting, frost prediction for orchards, etc.), EVA, ANGE
  - ✳ monitoring pollution, floods or fire, FLUMINANCE
  - ✳ characterization and simulation of agricultural landscapes, ORPAILLEUR
  - ✳ detection of land use changes and study of the relation of these to groundwater quality, ORPAILLEUR
  - ✳ modeling of land use / land cover changes, STEEP
  - ✳ study of the properties of seismic faults, earthquake modeling and hazard simulation, TITANE

Culture of microalgae - DEFI « Algae in silico »

- Microalgae
  - richness in proteins, lipids, vitamins, antioxidants...
  - biofuel, chemistry, cosmetics...
  - human or animal nutrition
  - better yield than rape
- Inria Project Lab
  - "Algae in silico" : from the gene to the industrial process
  - 7 Inria teams involved
  - INRA (LBE and LIPM), CNRS-SU (LOV), IFREMER (PBA), CentraleSupelec (LGPM)



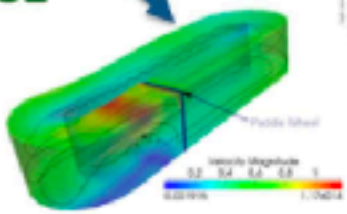
BIOCORE, DYLISS, ANGE, IBIS, COMMANDS, McTAO, PLEIADE

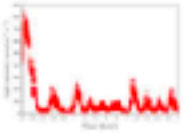
A multidisciplinary project

$$(NS)\begin{cases} \operatorname{div}\underline{\mathbf{u}} = 0, \\ \dot{\underline{\mathbf{u}}} + (\underline{\mathbf{u}}.\nabla)\underline{\mathbf{u}} + \nabla p = \mathbf{G} + \operatorname{div}\underline{\Sigma}, \end{cases}$$

Modelling free surface hydrodynamics
(Galerkin-type approximations of NS)

ANGE





Light perceived by a cell

Lagrangian reconstruction

Bi$\acute{e}$co$_2$re

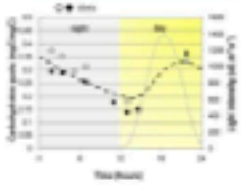
Optimize productivity
(biofuel + compounds)

Pleiade

Lbe

Mc道

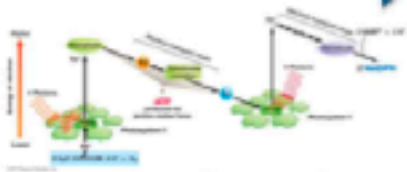
Impact on metabolism



ibis

DyLISS

PBA



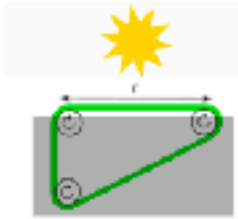
Impact on photosynthesis

$$\dot{A} = -k_1 A + \frac{B}{\tau}$$
$$\dot{B} = k_1 A - \frac{B}{\tau} + k_2 C$$
$$\dot{C} = -k_2 C + k_3 \sigma I B$$

Commands

Artificial reconstruction

ANGE Bi$\acute{e}$co$_2$re



LGPM

inalve

- AI for protein function prediction

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Other contributions (cont'd)

- Monitoring of infrastructures
  - monitoring and localization of damages on civil structures (bridges, towers, roads, etc.), I4S
  - modeling of geophysical flows, for oceanography, meteorology, sediment transport modeling (estimation of sustainability of infrastructure such as canals, bridges, etc.), ANGE
  - study of concrete carbonation and corrosion, prediction of evolution of civil engineering structures, RAPSODI
- Water:
  - simulating effects of landscape structure, farming system changes and their spatial arrangement on stream water quality, LACODAM
  - models for sustainable management of water consumption (game theory), NEO
  - detection of land use changes and study of the relation of these to groundwater quality, ORPAILLEUR
- CO2 storage
  - simulation of compositional multiphase flow in porous media with different types of applications, in particular reservoir/bassin modeling, and geological CO2 underground storage, ALPINES
  - modeling photosynthesis-based CO2 fixation in microalgae, BIOCORE
  - geological sequestration of CO2, SERENA
- Financial system
  - investigate the condition of apparition of a monetary economy in a more ecological framework provided with the assumption that the market is made up of a finite number of agents having a bounded rationality and facing a time constraint, MNEMOSYNE, MATHRISK

A contrasted situation

+ Many EP involved in research activities related to SD
+ A growing trend
- Few demands arrive to DGD-S
- Not raised during evaluation seminars

Strategy

- Sustainable development implies profound changes
- Research & « all activities »
- Organization / incentive actions
- Available means
- Lean ICT

A riddle

« La recherche et l'innovation doivent apporter leur concours à la préservation et à la mise en valeur de l'environnement. »

« Research and innovation must support the preservation and enhancement of the environment. »

A complex situation

- ICT charged with
  - Unfulfilled promises (less travel,…)
  - Carbon footprint (IoT, streaming,…)
  - Limited recycling, rare metals, rare earths
  - Education (teacher versus computer)

- A demand of some people
  - Students interested in sustained development (SD)
  - Researchers want their scientific themes in accordance with SD
  - Another way to work (air travel / videoconferencing, lifespan…)

Several constraints

- Time scales
  - Emergency versus acceptability
  - A long-term challenge (2030, 2050…)
- Spatial scales
  - North versus south - developed/developing countries
  - CO2, NH4 quickly uniformly spread
  - Global solutions versus local/personal initiatives
- Different levels of maturity
  - Research activities versus related activities
  - Bottom up versus top down
  - The good question : what am I ready to do ?
  - Rapid evolution but a limited proportion
  - Very difficult to find a agreement between pros & cons

Role of the ADS

« Environment, sustainable development & energy »

- Transversal role
  - many teams concerned
- Thematic role (research theme 5.1 - Earth, Environmental and Energy Sciences)
  - AIRSEA, ANGE, CASTOR, COFFEE, FLUMINANCE, LEMON, MAGIQUE-3D, SERENA, STEEP, TONUS
- Promote/encourage initiatives
- Partnerships
  - preliminary discussions
  - matching EP/partners
- Propositions/evaluations

Towards a 6th domain ?

- Several themes
  - Earth & Environmental Sciences
    - ✓ modeling & simulations
    - ✓ geophysical flows, agriculture
  - Energy Sciences
    - ✓ renewable energies (optimization)
    - ✓ nuclear fusion, storage
    - ✓ from producers to consumers (optimization, AI)
  - Lean ICT
    - ✓ smart grids, cities, mobility
    - ✓ networks, architecture

Or many project-teams, DEFI, AEx…

Towards researchers

- Researchers (many?) want their scientific themes are in accordance with sustainable development
  - inside their team
  - large inflection
- Find individual solutions
  - exploratory actions
  - mobility in another team
  - possible because SD has consequences everywhere
- Participatory sciences
  - questions related to SD are complex
  - explain the scientific approach, research & innovation are a part of the solution to SD related problems
  - rational/scientific knowledge

Strategic fields / scientific collaborations

- EC: Green Deal
  - very ambitious, few themes & high impact
- Modeling/simulation/optimization for environment
  - climate / oceanography & natural hazards
  - renewable energies
  - virtual twin of the ocean
- Lean ICT
  - HPC, footprint of AI, green coding…
  - see below
- Agriculture
  - enhance collaborations with INRAE, january 2020 (workshop + seminar)
  - small scale : biology, bio-informatics & large scale : agronomy, impact of climate changes, hazards, systemic scale
- Many partners : ADEME, BRGM, THALES, TOTAL, ShiftProject…
- Not an exhaustive list

Numérique frugal

- « Feuille de doute » (M.-H. Pautrat, P. Sturm, F. Desprez, JSM)
  - transmise à la DG
- Thème structurant
  - Inria est attendu (ADEME, CNNum, DGE…)
  - niveaux national et européen : une place à prendre
  - recherche publique et privée, think tank…

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1. Recherche
   - voir slide suivant
2. Innovation
3. Médiation et compétences
   - numérique et environnement
4. Labélisation / certification

Numérique frugal (suite)

- Un DEFI
  - beaucoup de choses à définir / à préciser

Les grandes lignes

- Recherche
  - grands systèmes distribués & réseaux
  - architecture & compilation
  - algorithmique & programmation
  - études systémiques

- Structuration (liminaire)
  - 2 axes : réduction de la consommation (HPC, réseau, architecture, algorithmique),
  - analyse des cycles de vie, étude systémique
  - niveaux national et européen
  - recherche publique et privée, think tank…

L’environnement et le monde d’après ?

- Volonté de « discontinuité » et besoin de « continuité »
  - réflexes versus réflexion
- Conséquences incertaines
  - urgence économique ?
  - important versus contingent ?
  - individuel versus collectif ?
- L’ampleur de la tâche (empreinte carbone)
- Enclencher un cercle vertueux
- Déplacements versus « à distance »
- Souveraineté versus partenariats (européens)

Conclusion

- Une ligne de crête
- Une politique volontariste
  - de bas en haut plutôt que de haut en bas
  - moyens incitatifs
- Développer
  - le « numérique frugal »
  - le « numérique pour l'environnement »
- Favoriser
  - les changements thématiques
  - les projets innovants
- CE : Green Deal

Engageons-nous !