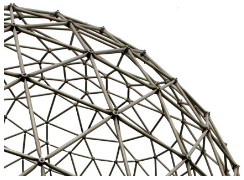
# Autonomic Management for the Emerging Internet: Current State and Key Challenges

Prof. George Pavlou
g.pavlou@ee.ucl.ac.uk
http://www.ee.ucl.ac.uk/~gpavlou/
Networks and Services Research Laboratory
University College London

# The Internet Today

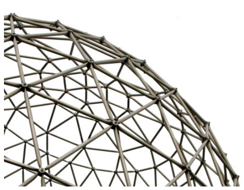
- The Internet plays a central and vital role in our society
  - Work and business, education, entertainment, social life, …
- Victim of its own success, suffering from ossification
  - Technological innovation meets natural resistance e.g. no ECN, no IPv6, no mobile IP, no inter-domain DiffServ, no inter-domain multicast, etc. etc.
- Services such as P2P, VoIP, IPTV, user generated content, emerging ones, pose new requirements on the underlying network architecture
  - Increased dynamicity, spontaneity and fluidity
- Big growth in terms of the number of inter-connected devices but slow growth in innovation and new services



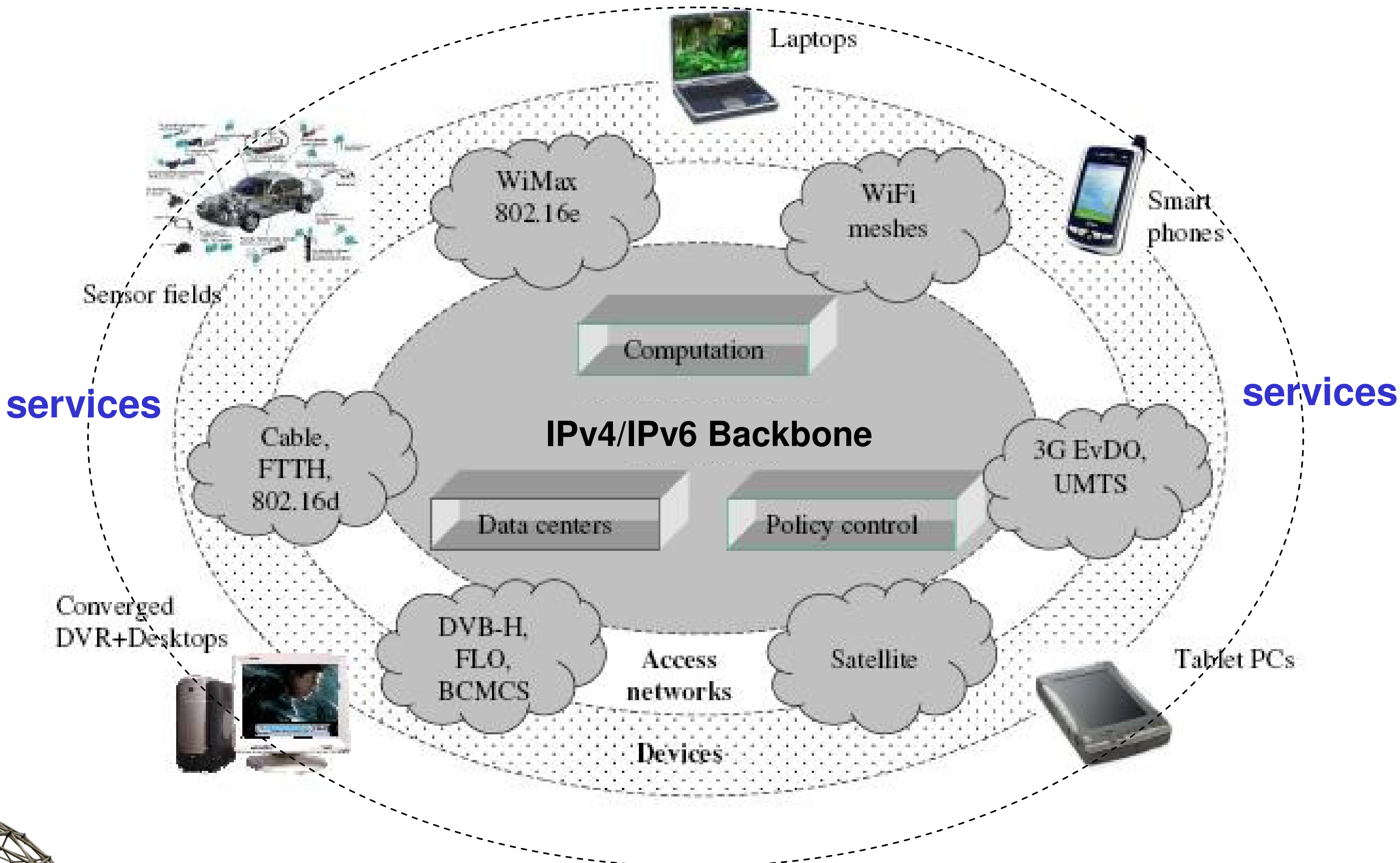
# History of Internet Changes

- Changes were possible when the Internet was still an academic research network
  - i.e. until 1993 when the WWW turned it to a commercial inter-network that underpins the “information society”
- Key changes in that period were the following:
  - 1982 DNS, 1983 TCP/IP instead of NCP, 1987 TCP congestion control, 1991 BGP policy routing, 1991 SNMP, 1993 CIDR
- No significant changes since then apart from MPLS which has been deployed *in addition* to plain IP

- Research efforts towards the **Future Internet**: evolutionary & clean-slate approaches, including autonomic management



# The Emerging Internet



# Key Requirements

- Better mobility support
  - Impact on addressing – location / ID separation
- More flexible and reliable routing (esp. inter-domain)
  - Multi-path as opposed to current single path
  - User-selected paths with different QoS characteristics
  - Combine content discovery and routing – clean slate redesign
- Better security, DoS attack and spam protection
  - Possibly other paradigms of identity/presence, e.g. default-off
- Better service-aware resource control
  - Service-aware mapping of traffic to resources => better QoS
- Self-management capabilities
  - Self-configuration, optimisation, healing, protection

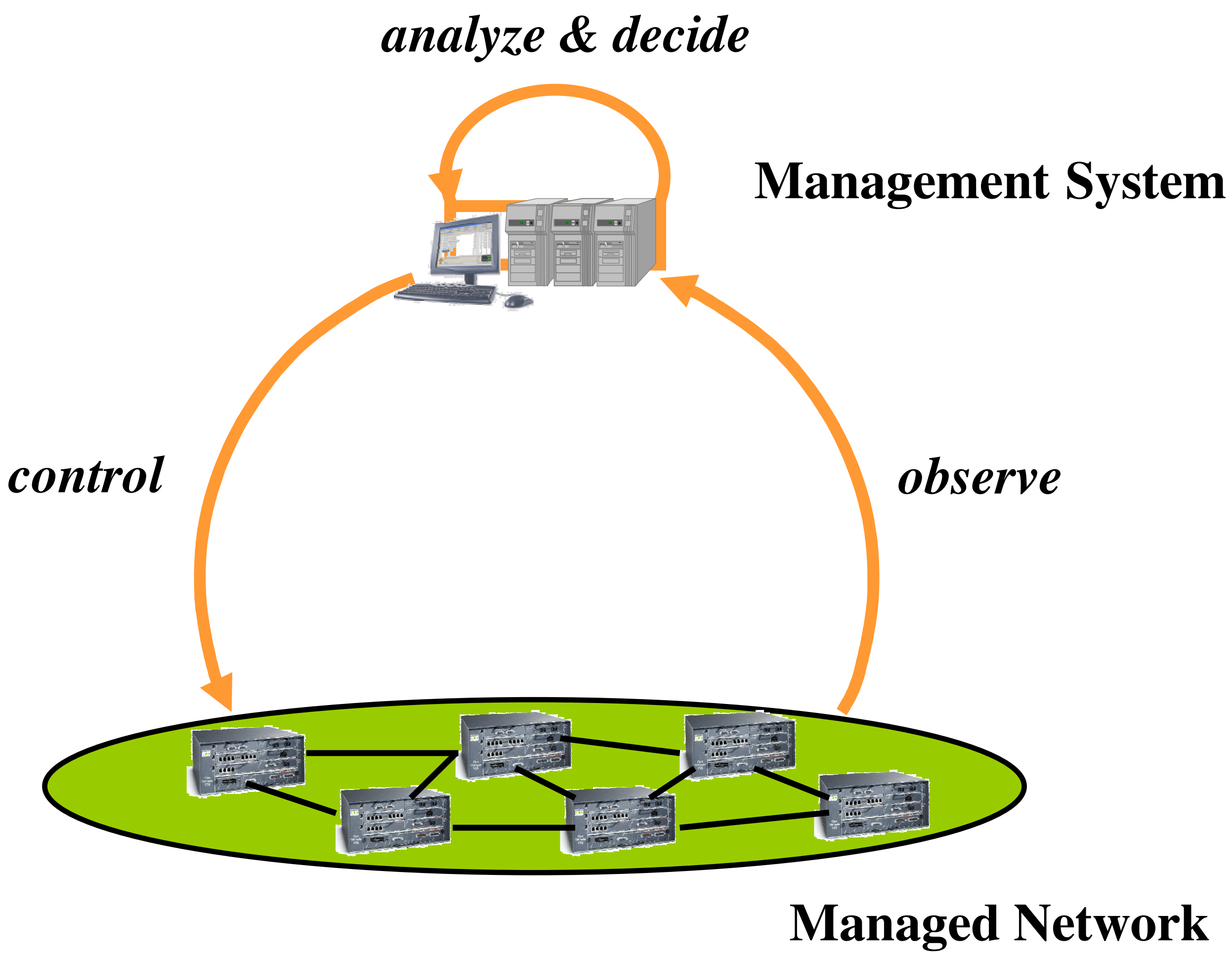
# Flexible Addressing and Routing

- Location / ID separation
  - Routing on locators, final delivery based on ID => better support for mobility
- Multi-path routing, paths with QoS characteristics
  - Better resilience, load balancing / use of resources
  - Applications/services can choose based on their requirements
- Combine content discovery and network-level routing
  - Data-oriented future network architectures
  - Radical redesign and combination of DNS and routing

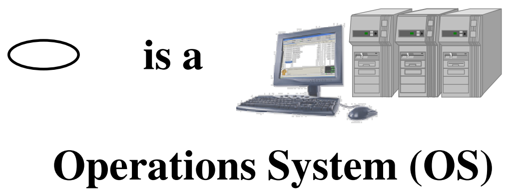
# Future Internet Functionality

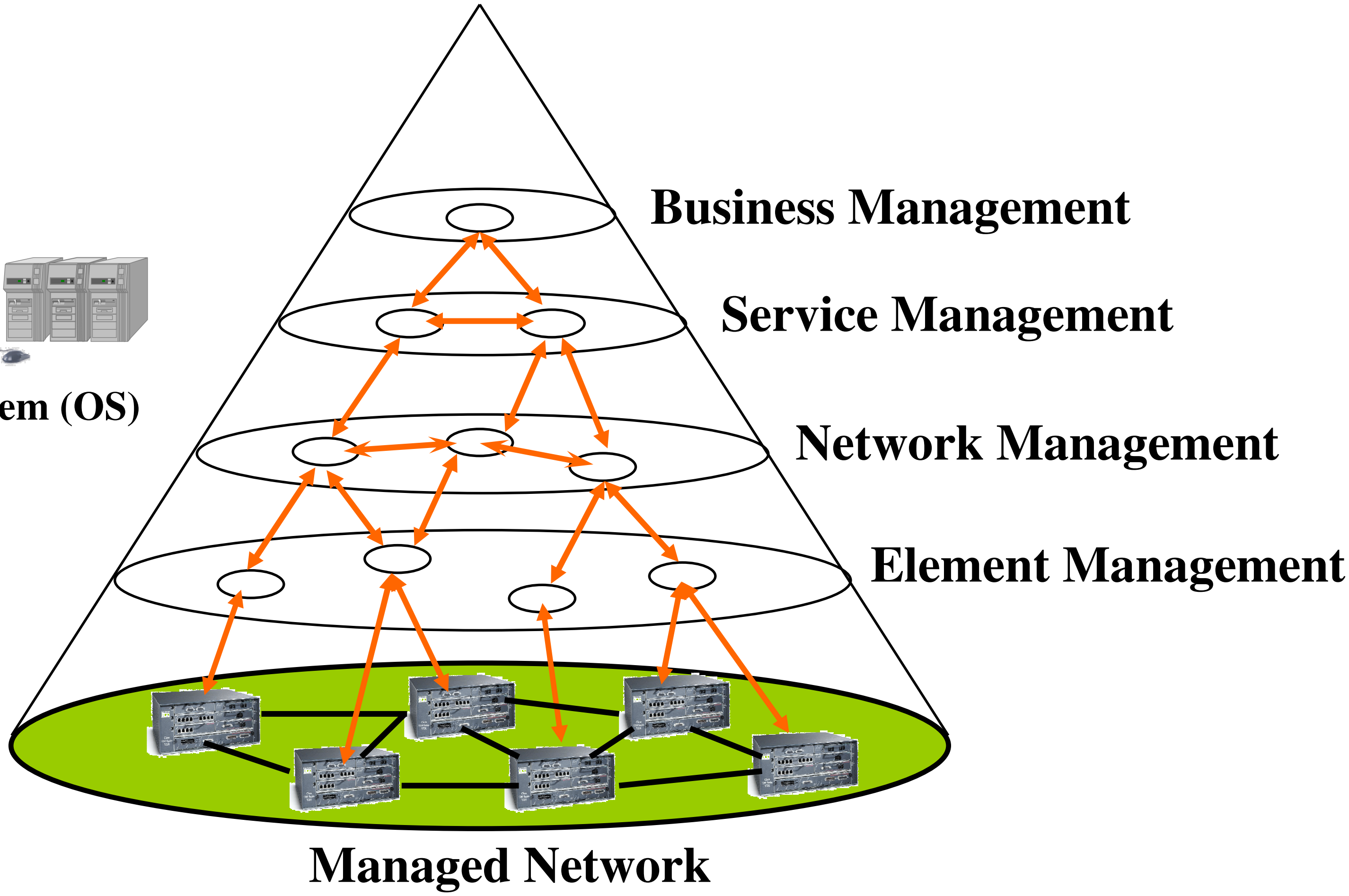
- Network layer
  - ID-locator separation
  - Source-influenced / user selected routing
  - Content-based routing combined with content ID resolution
- Application layer
  - Generalized event infrastructure, content-based routing
- Network management
  - Observability: acquire information in real-time for reasoning about network events - “in-network management”, performance auditing
  - Self-* capabilities,
- New network capabilities
  - Virtualization, programmability, network storage & computation

# Current Management Models - Centralized



# Current Management Models - Hierarchical



# The Foibles of Today's Internet Management

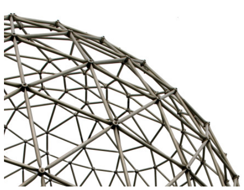
- No management technology that is good-enough for all management tasks
  - SNMP only suitable for basic monitoring
  - Vendor-specific approaches: Cisco's NetFlow / CLI, etc.
- Mostly non-automated approaches that require **a lot** of human input
- Most important, no closed-loop management
  - Configuration for a resource provisioning cycle
  - Data gathering, off-line calculation and eventual reconfiguration
- No automated adaptive distributed management

# Autonomic Management & Networking

- Autonomic Management is intrinsic in IBM's Autonomic Computing vision (2003):
  - "Systems that can manage themselves given high-level objectives by administrators"
- Extending autonomic management from individual elements to the collective self-management of networks of such elements results in Autonomic Networking
- Autonomic networks can configure, optimize, heal and protect themselves given high-level goals
  - Self-* properties of self-configuration, self-healing, self-optimization and self-protection (CHOP)

# Degrees of Autonomy

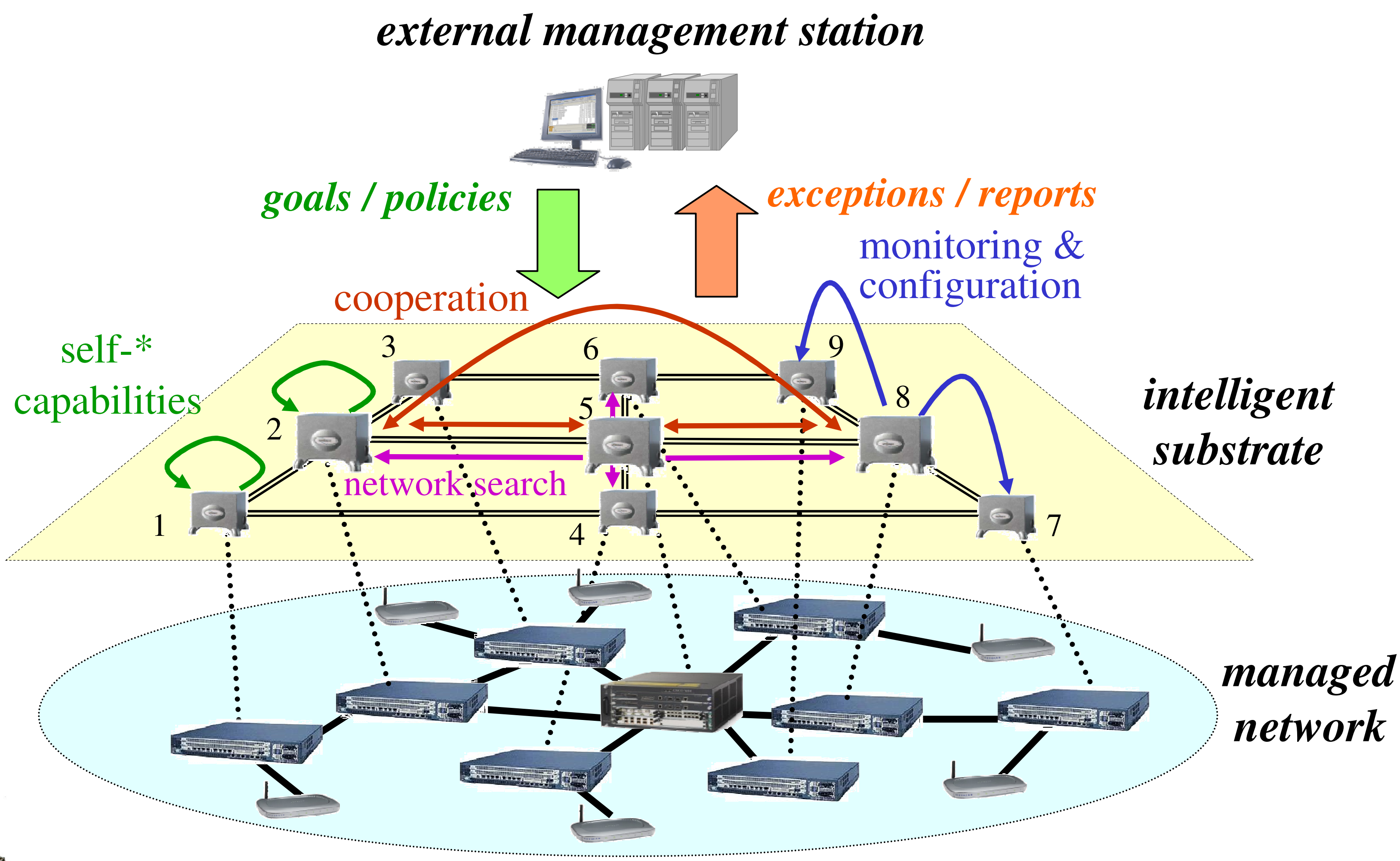
- A system or network can be:
  - Totally unmanaged
  - Planned / configured in a predictive manner – this is how most ISPs run their networks today
  - Planned in a predictive manner but also adaptive to emerging conditions e.g. unexpected traffic patterns – closed-loop control automated management
  - Adaptive to emerging conditions but also autonomic – able to understand and analyze its environment with little or no external input
- The difference between adaptive and autonomic lies in:
  - Intelligent operation through learning and reasoning
  - In-network operation that makes possible real-time feedback control loops



# Self-Management Architecture

- Architectural preview of the solution space:
  - Distributed-management through a set of dynamically-chosen nodes operating in the network for specific tasks – management substrate
  - Collaborative decision making by acquiring knowledge, learning and reasoning – lightweight cognitive operation
  - Orchestration of the built-in management intelligence by setting high-level directives to the management overlay which will “parametrize” the built-in algorithmic intelligence
- “Collapse” of (the majority of) the management plane within the network itself in a number of substrates
  - This approach is essential with infrastructure-less networks, e.g. mesh, ad hoc etc., for which “external” management is not possible

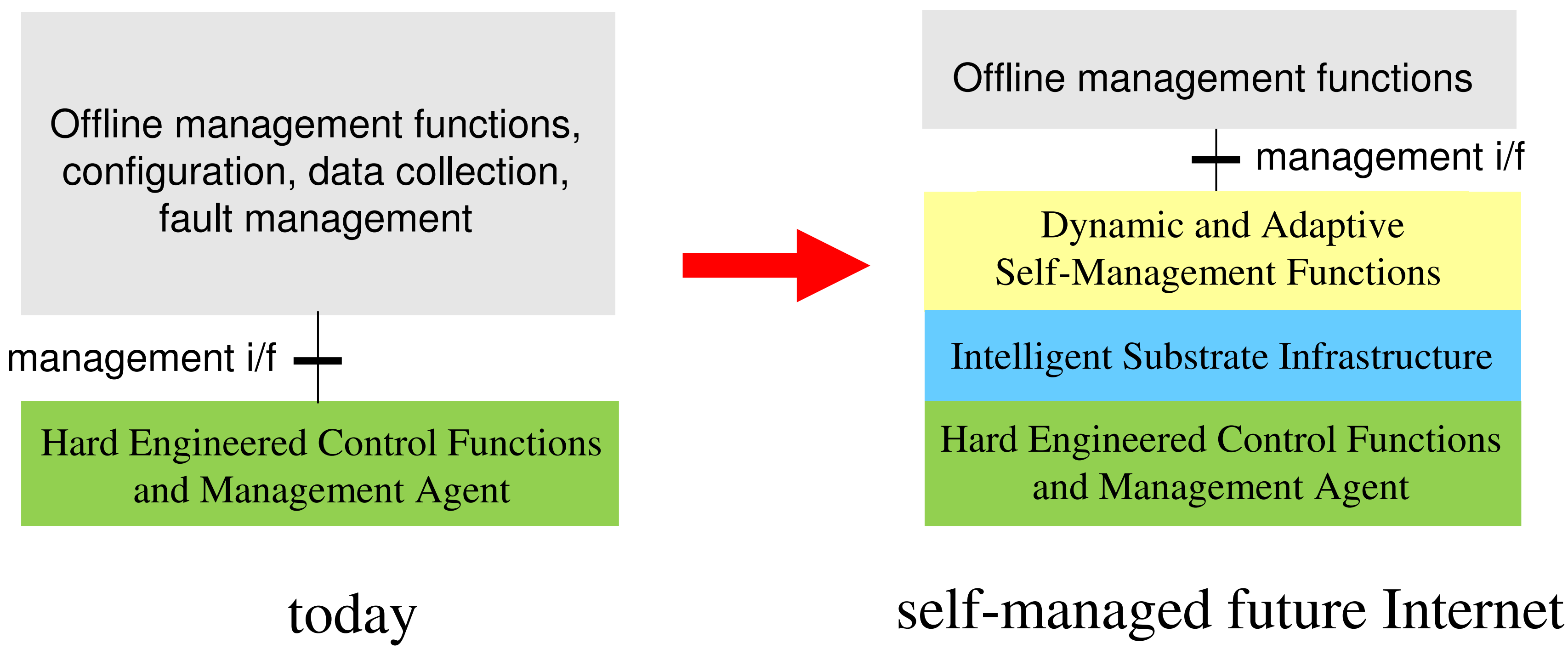
# The Management Plane as Part of the Network: a Set of Intelligent Substrates



# Intelligent Substrate Concept

- The term substrate is better than plane or subplane:
  - Substrate in biology is defined as "*the natural environment in which an organism lives*"
  - Substrate in neuroscience is defined as "*the set of brain structures that underlies a specific behavior or psychological state*"
- Intelligent substrates do exactly that for the network
  - They form its natural environment given their continuous resource management
  - Each substrate underlies a specific network behavior
- The virtual union of knowledge in all intelligent substrates is equivalent to Clark's knowledge plane

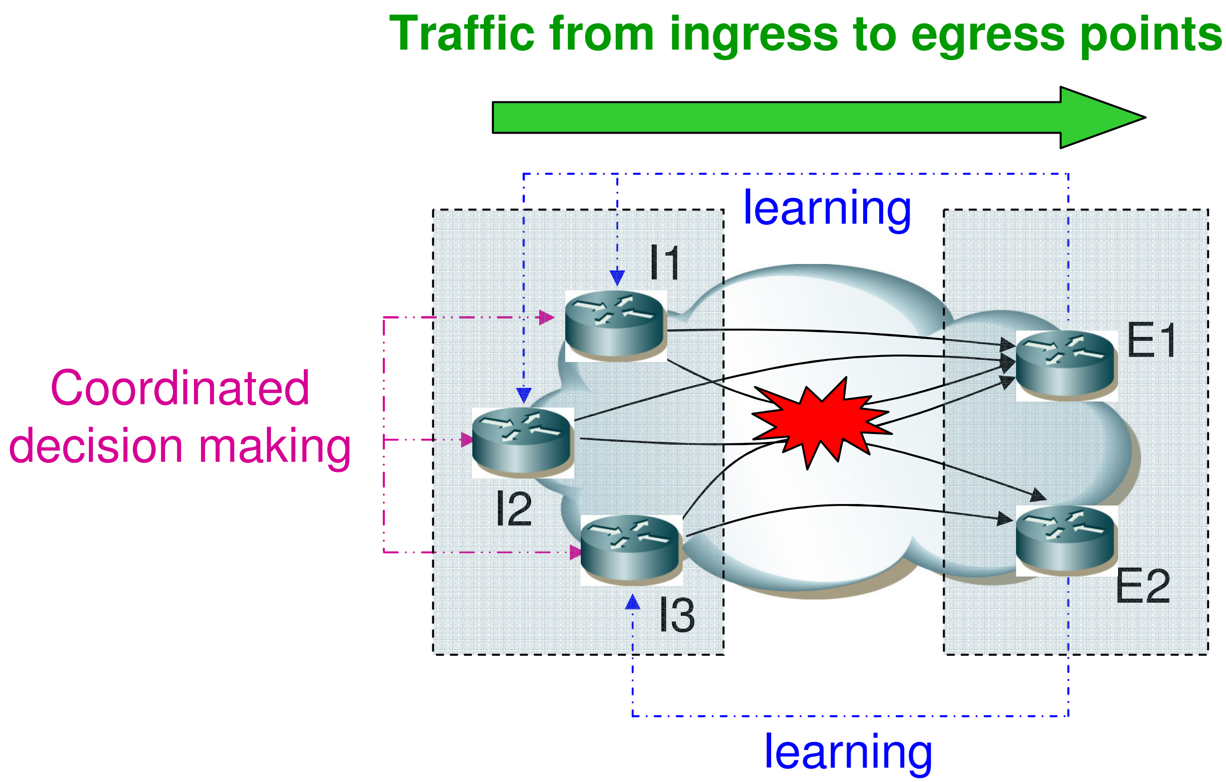
# Placing Management Intelligence



# Autonomic Management for the Future Internet

- With built-in autonomic management functionality that will be intrinsically designed together with it, the Future Internet will:
  - Self-traffic-engineer in the face of constantly changing traffic patterms in order to optimize QoS – this will be of paramount importance in the case of source-influenced routing
  - Self-reconfigure to recover from failures, extending today's similar functionality with "parametrizable" intelligence
  - Self-reconfigure to mitigate DoS attacks etc.
  - Produce performance auditing data on request
  - Produce information about what is happening and why – real-time in-network observability as opposed to "stale" MIB data
  - …
- Intelligent network management that is built-in together with the networking functionality and not as an afterthought

# Example of Coordinated Dynamic Traffic Engineering



# Elements of Autonomic Networking

- Autonomic network: a cognitive network that can understand and analyze its environment and plan and execute appropriate actions with little or no human input
  - Monitoring its surrounding environment – context-awareness
  - Knowledge acquisition, learning and reasoning
  - Distributed decision making under uncertainty with partial network views
  - Achieving stability and convergence despite distributed semi-independent decision making
  - Being able to negotiate and resolve conflicting requirements/decisions
  - Being externally influenced by high-level goals and also being able to recover from dynamically arising conflicts
- We discuss salient features and key research challenges for autonomic networks next

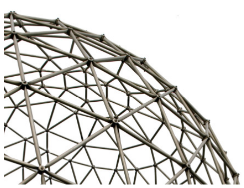
# Scalable Decentralized Operation

- Scalable distributed monitoring approaches are essential as relevant information is the basis for adaptation, self-optimization, identifying faults and self-repairing, etc.
  - There is a body of work in this community that can be adapted to serve the needs of autonomic networks
  - Need to be able to control the trade-off between accuracy and monitoring overhead
- Scalable adaptive organization of the management overlay is also essential for decentralized operation
  - Again there is a body of work in this and other communities, e.g. P2P systems, MANETs, that can be adapted and used
  - *p-median* and *p-center* problem solutions can also help

# Learning and Reasoning

- Machine learning by a single agent in static environments is well studied but autonomic systems typically involve multiple continually adapting agents
  - Knowledge from other domains will need to be imported and adapted
  - Learning in multi-agent systems in the distributed AI community
  - Optimization in multi-agent environments an unsolved issue

- Reasoning and extending existing knowledge is the key to machine intelligence
  - Associated to the – still unsolved – general AI problem
  - Autonomic systems can employ limited intelligence without the need to wait for this fundamental breakthrough in reasoning



# Stability and Convergence

- Distributed decision making with partial network views can be inherently error-prone, with overall stability and convergence being key issues that need to be addressed
  - How can distributed autonomic behavior can coordinated?
  - How can the overall system behavior be determined from the autonomic component interactions?
  - Advances in theory of robustness for autonomic systems is required
- Assuming only loose coordination at best, conflicting requirements and decisions of autonomic components will most probably be the case
  - How can these be conciliated?
  - Negotiation approaches & algorithms need to be developed and game theory may be of help in this area

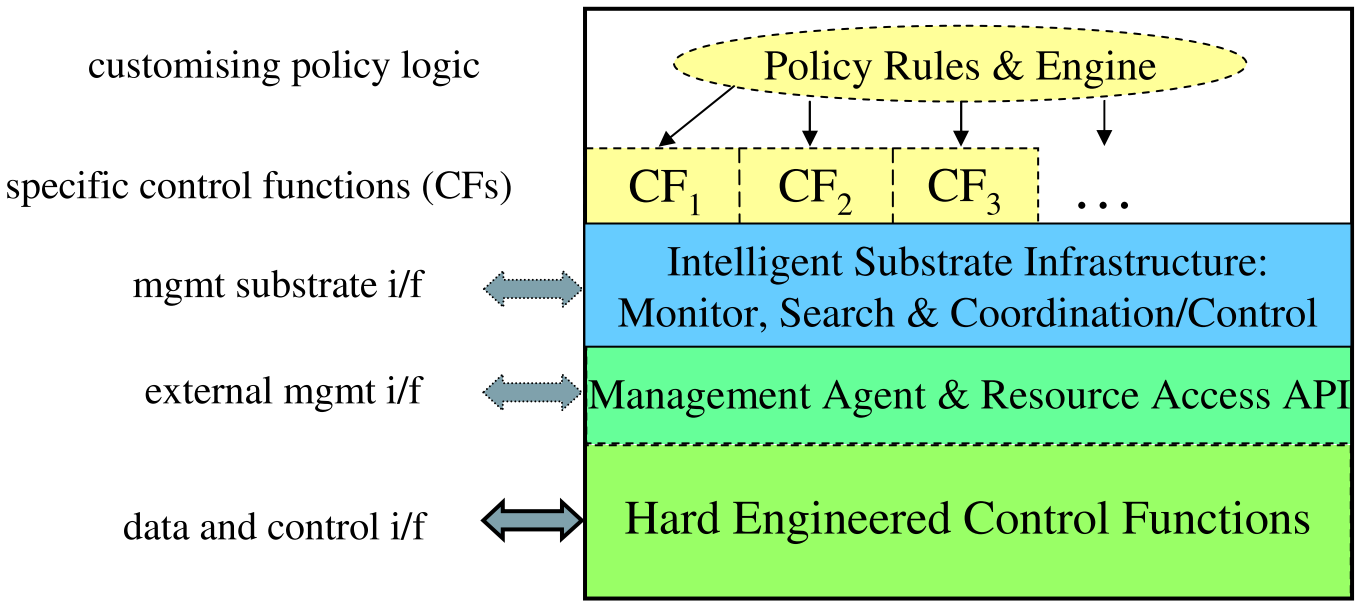
# Dynamic Policy Conflict Resolution

- Algorithmic intelligence in autonomic devices will be controlled through policies expressing high-level goals
  - Controlled “programmability” of autonomic nodes to govern policy-driven closed loop control feedback systems

- Policies in various levels of abstraction for different level autonomic control loops will be required
  - Difficult to even do static policy conflict analysis
  - Breakthroughs in policy analysis, refinement and static conflict resolution will need to be extended for autonomic systems

- But how can dynamic real-time conflicts be handled?
  - Difficult problem, context-specific solutions may be possible

# Self-Managed Node Architecture



# Summary

- The Future Internet will possibly be more dynamic, allowing for more user control
  - It will pose much more difficult management challenges
- Autonomic management will allow management to work closely with control functions, enabling self-management via closed loop feedback control
  - Better management functionality that is not an afterthought
  - Potentially better services and cost-cutting
- We have already some of the elements of autonomic management but we need advances in various areas
  - This community is well-placed to make IMPACT!