monami
3rd International ICST Conference on Mobile Networks & Management 2011

Autonomic Mobile Network and Service Management for the Future Internet

Dr. John Strassner
CTO, Software Lab, Huawei

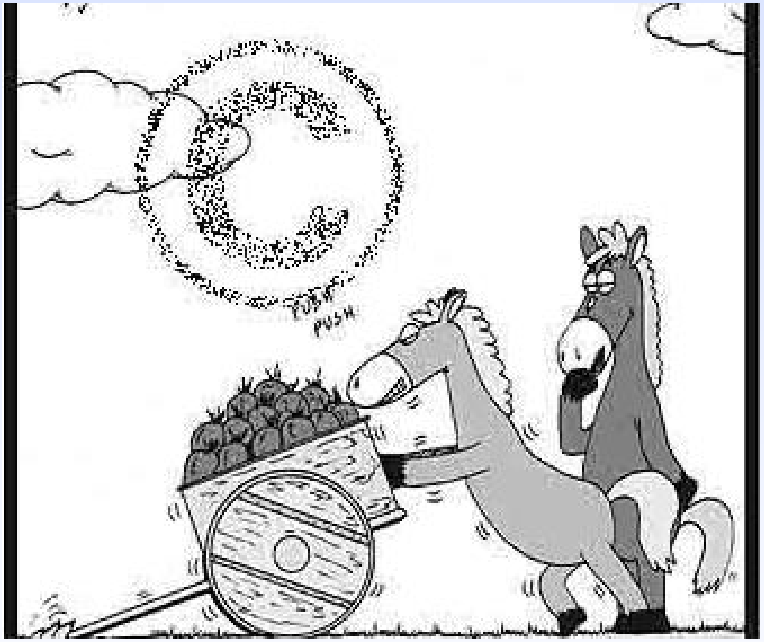
Motivation: Technical Factors

Some Depressing Analyst Quotes

- 84 percent of enterprises have *experienced a security breach in the last year* (InformationWeek)
- 70 percent of companies have *not deployed a full business continuance plan* (Gartner)
- *Approximately 40% of all availability issues are user error and process related* (Gartner)
- *70 percent of manual service configurations fail the first time around* (The Yankee Group)
- *60 percent of network records contain at least one error* (The Yankee Group)
- *40 percent of network assets are stranded* (The Yankee Group).

Network Management Data

- Yes, the Internet Architecture is ossified
- A bigger problem is that there is NO scalable management approach
  - The state of the art is rigid…
  - …as is our thinking! SNMP has failed, but if we can wrap it in XML, all of our problems will disappear! ☺



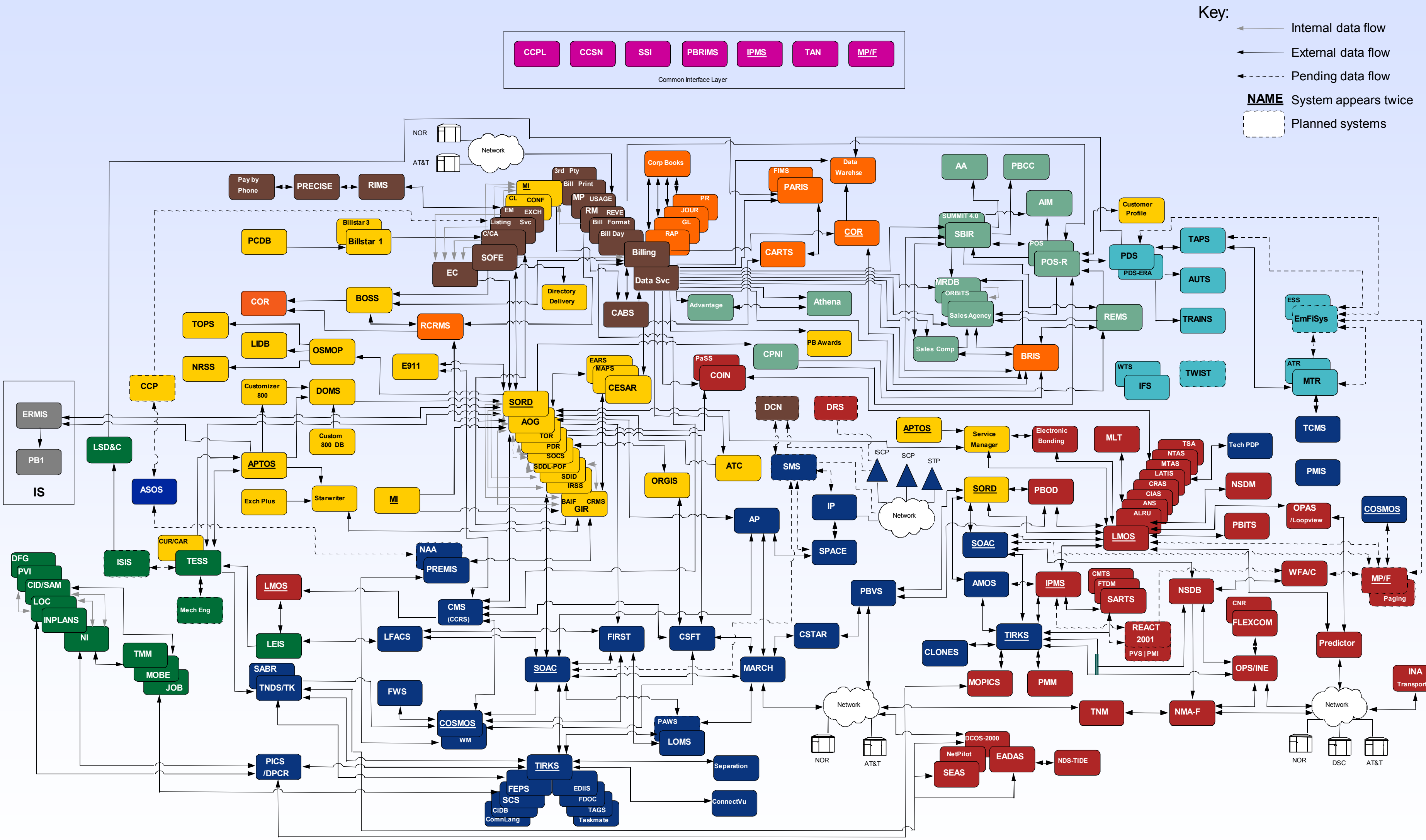
  - Layers must be good. That’s why we are so concerned with cross-layer design. ☺
  - No vendor will retool their device OSs unless there is a compelling business reason for them to do so

Dirty Slates

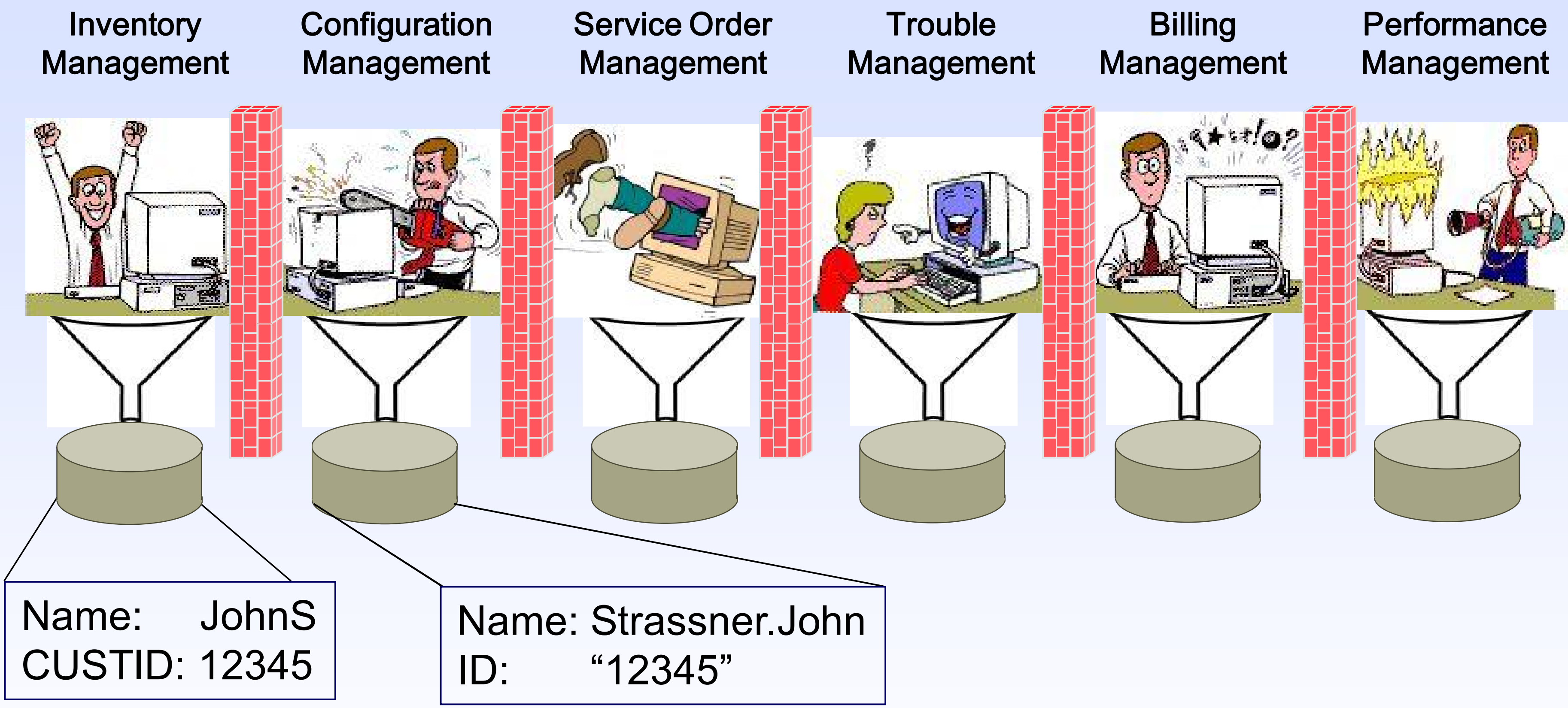
- Ignoring everything and starting over is not economically feasible
  - Technological innovation is good, as long as it is accompanied with business needs
  - We can't even roll out IPv6 successfully, and now we're going to talk about
    - YAADA *(Yet Another Addressing Definition Architecture)*
    - YAPSA *(Yet Another Protocol Suite Architecture)*
    - YASA *(Yet Another Security Architecture)*

    …
  - No standard approach to representing and sharing *knowledge* exists
    - *Until this is solved, automation will be limited at best*

A Traditional OSS/BSS



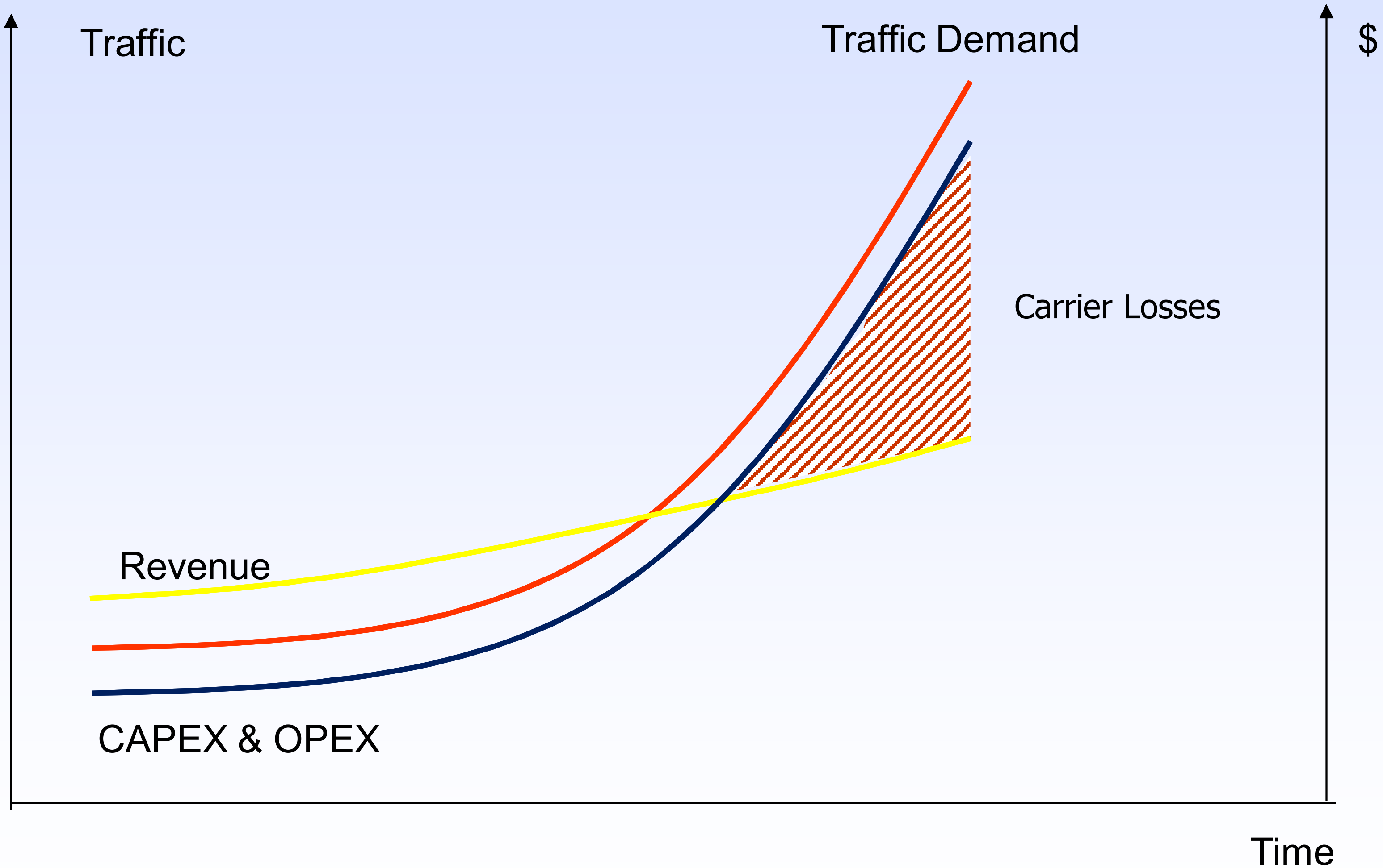
Shortcomings - Infrastructural



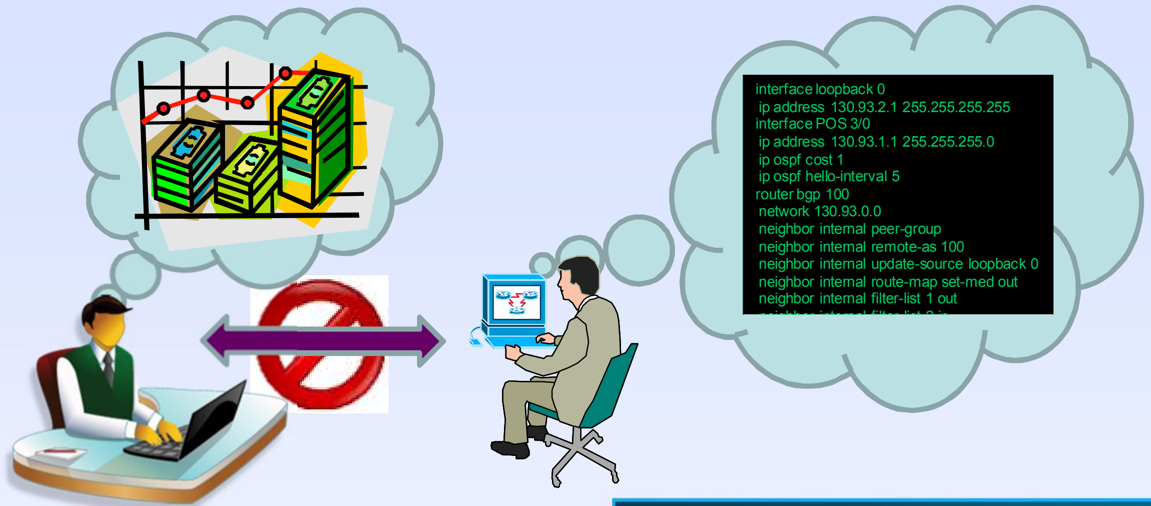
- Architectural issues
  - Data redundancy
  - Synchronization problems
  - Application authorization issues
  - Vendor and Application "lock in"
- Integration issues
  - Isolated Data Silos
  - Administrative nightmare
  - Integration/customization nightmare
  - Transition from legacy systems to a new OSS

Motivation: Economic Factors

This Is Not Sustainable!



Differing Semantics



Business View: SLAs, Processes, Guidelines, and Goals

System View: Device- and Technology-Independent Operation

Network View: Device- Independent, Technology -Specific Operation

Device View: Device- and Technology-Specific Operation

Instance View: Device-Specific MIBs, PIBs, CLI, etc. Implementation

Motivation: Societal Factors Skipped – See Appendix

Motivation: Context-Awareness

What Makes a Smart Phone *Smart*?

- What Makes the Phone *Smart?*
  - More memory and faster CPU? … NO
  - Chaining simple services together to build a more complex service? … NO
  - ***It must be able to behave more intelligently***
- Do We Value Intelligence?
  - Would you buy a “more intelligent” phone? … NO
  - This is why manufacturers concentrate more on features than ease of use and context awareness
- The answer is a smarter management system that can provide what Dr. Mark Weiser called “***calm technology***”

The Vision of Calm Technology

“

Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods existed

”

- Dr. Mark Weiser, Scientific American, Sep 1991

DEN-ng Context Definition

"The Context of an Entity is a **collection** of **measured** and **inferred knowledge** that describe the *state* and *environment* in which an Entity exists or has existed"

Motivation: Wisdom

Trend Analysis Reveals a Common Theme

- **Security** requires understanding at a data, object, application, and system level
- **IT M agement a SOA** r res an understanding of how da proc ff apps interact
- **Cloud Co** lity, which requires an tics of operatio
- **BI an** anding of data and how it relates a mprove decision-making
- **Mobility** requires a understa ding of context and how an application is being used
- **Enterprise 2.0, M2M, IoT** requires an understanding of how different apps and devices can better work together

Understanding of Data and Behavior

Cloud is Not a Panacea

The Promise of Cloud Computing

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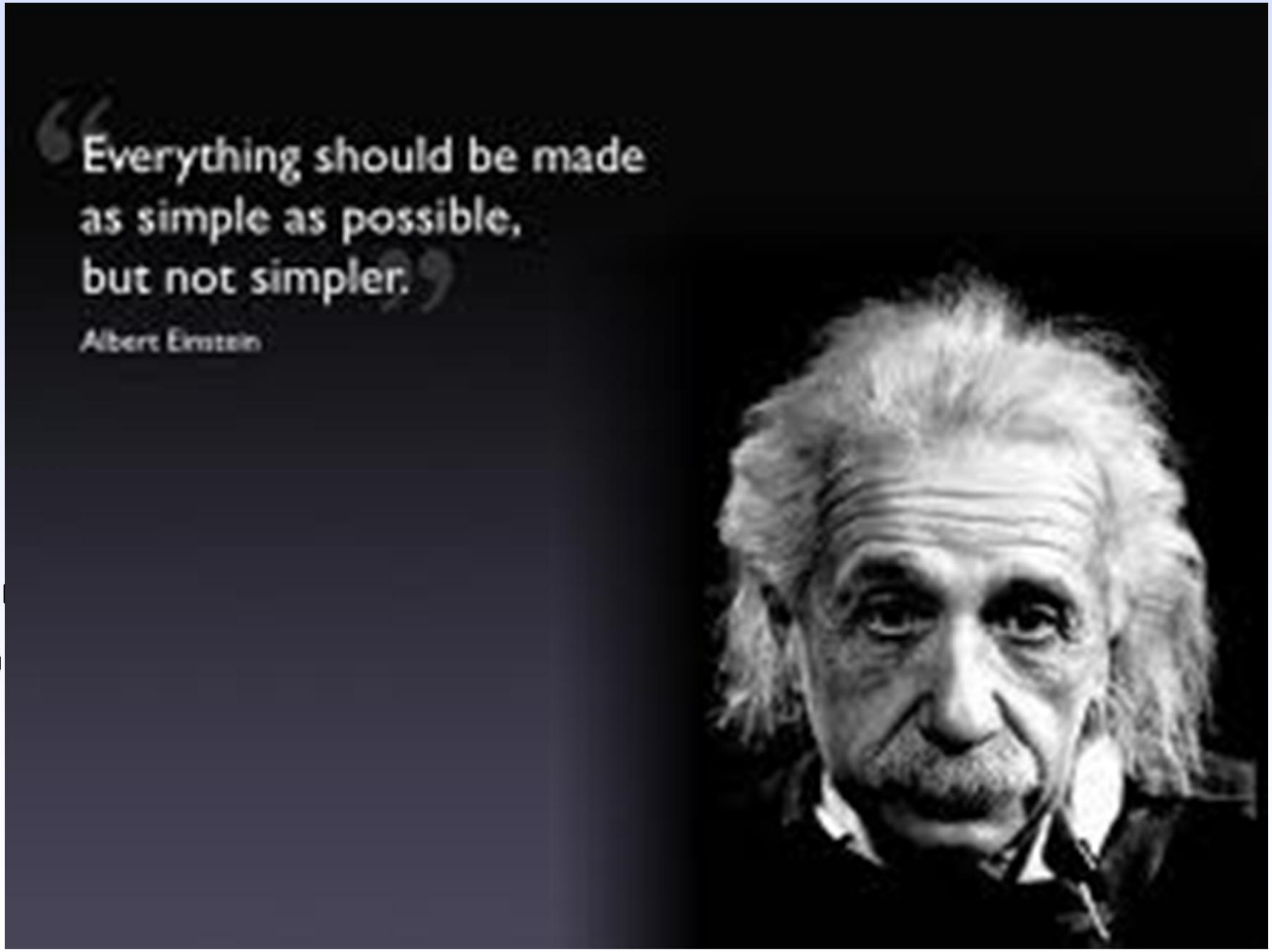
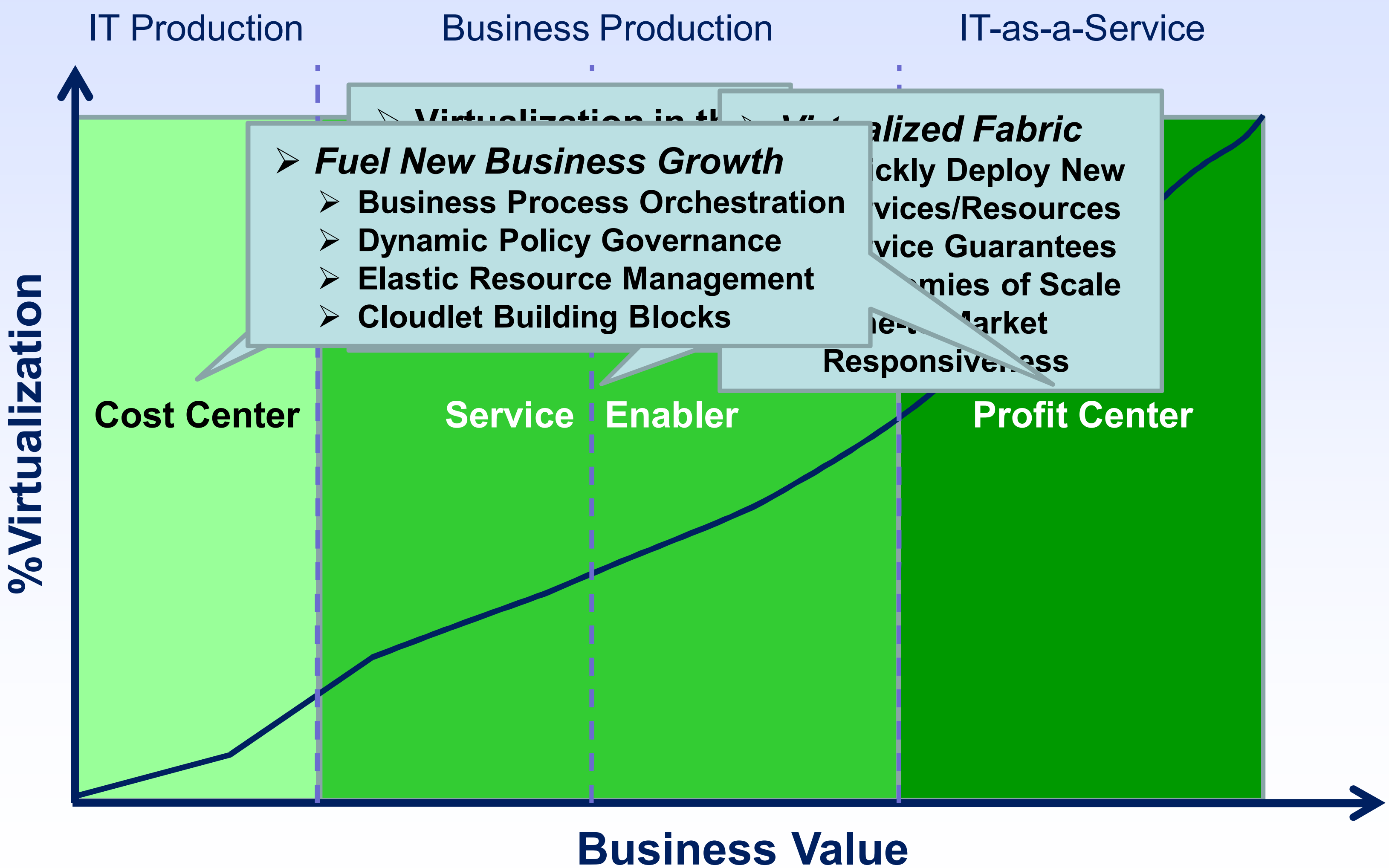


The Move to Cloud

- Easy, right? 
  - Applications must be changed from LAN to WAN
  - Security must be redone
  - Networks must be reconfigured
  - Policies must be redesigned and reapplied
- This is not a “one-time” cost!
  - Clouds change resource allocation dynamically in response to changing demand
  - Hence, to realize the most from clouds, resources must be dynamically allocated and released
  - This is difficult without being able to ***isolate workloads***
  - This becomes more difficult with virtualization!

Business Motivation

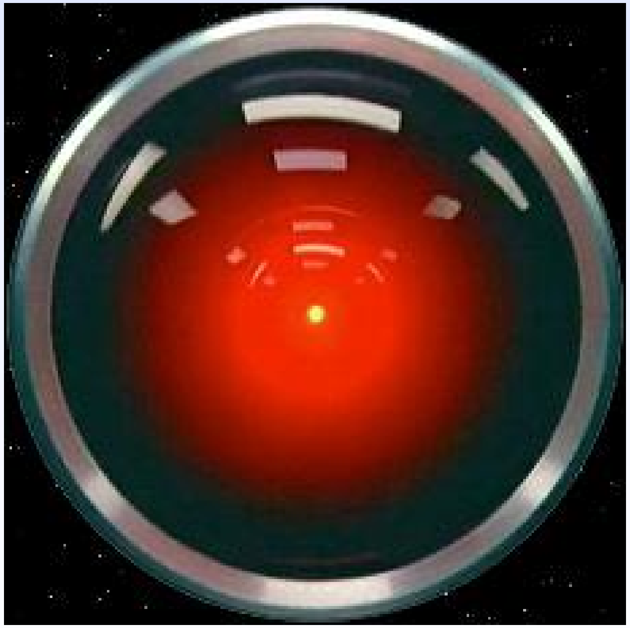


Autonomics 101

Future Vision of Autonomic Computing?

Machines will take over all management tasks, rendering humans superfluous.

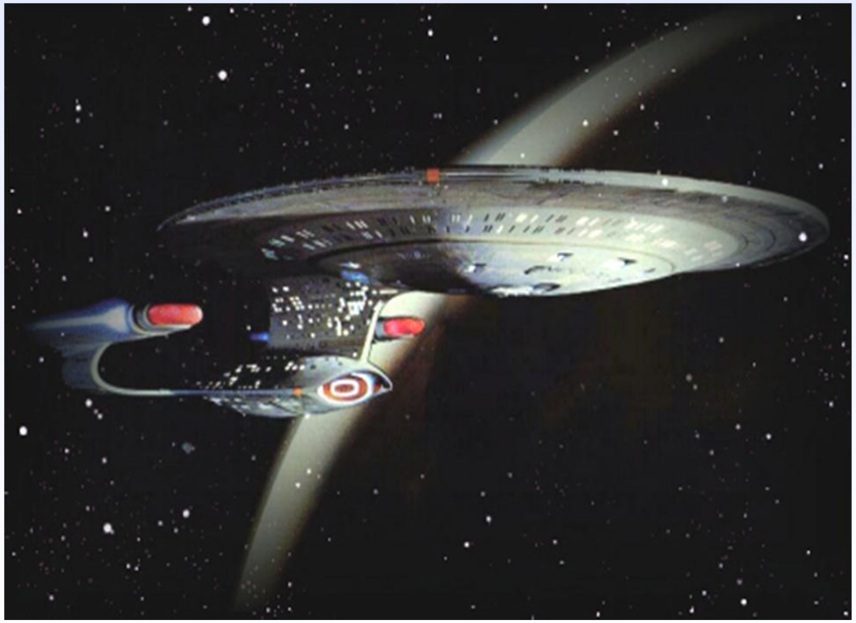
Hal 9000, *2001*



Wrong!

Future Vision of Autonomic Computing

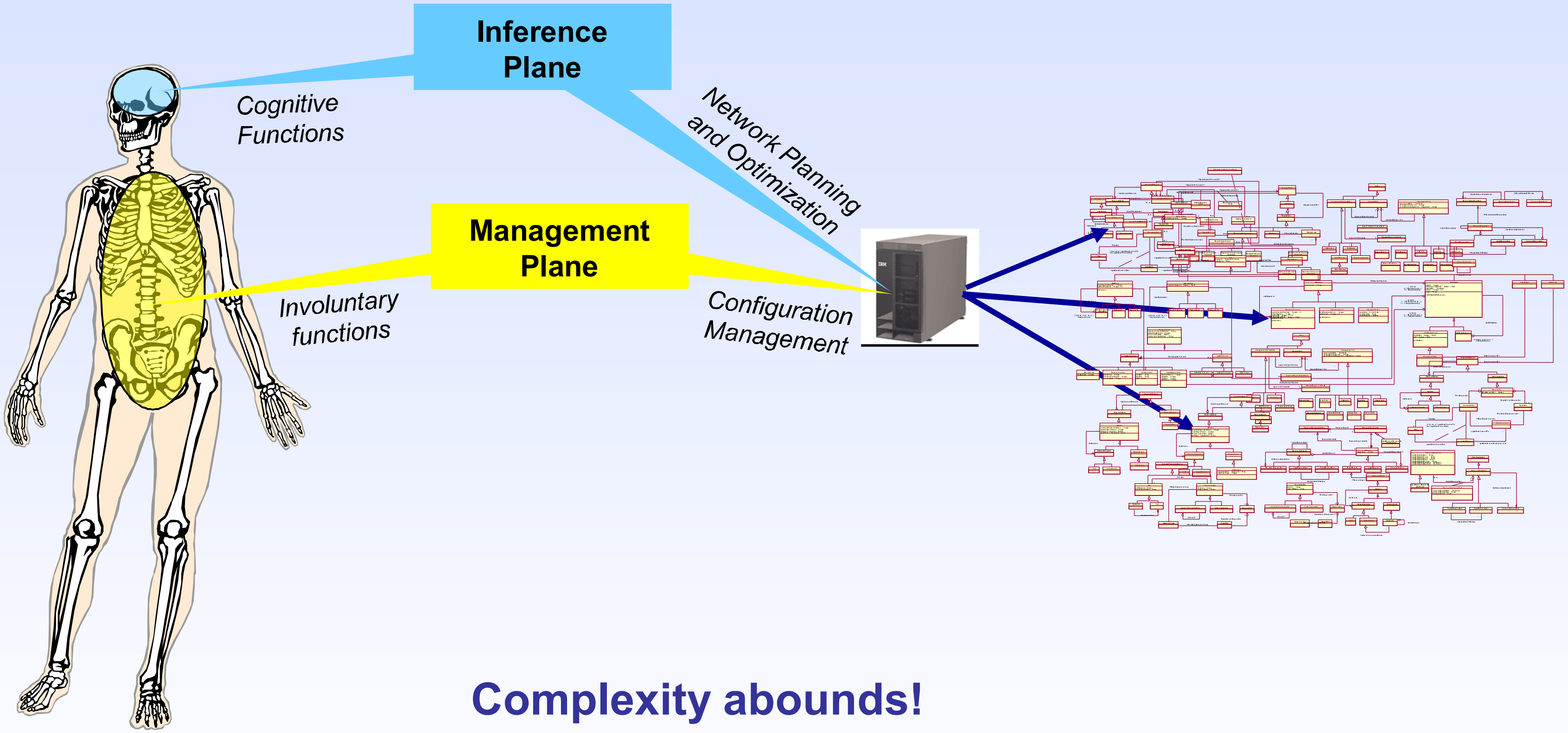
Machines will free system administrators to manage system at a higher level



Right!

Autonomic Networking

Biology, Sociology, and Economics can Inspire Better Networks!



Complexity abounds!

- *Technical* complexity: human body ⇔ technology, devices
- *Business* complexity: macro-economics ⇔ e- and m-Commerce
- *Behavioral* complexity: social interaction ⇔ service composition
- *Operational* complexity: healing ⇔ anti-virus, configuration management

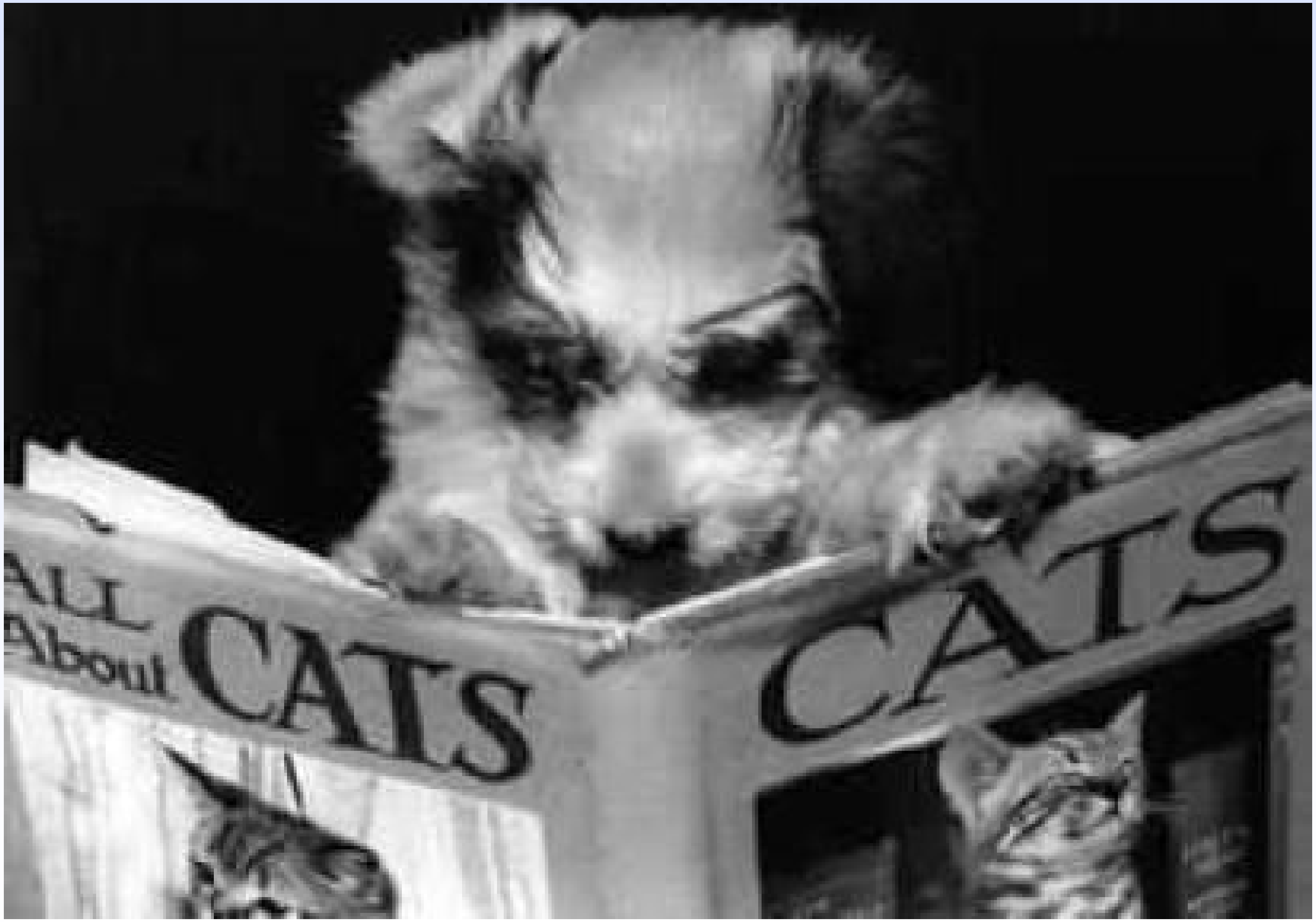
Autonomic Networking Definition

- An autonomic system is a ***self-governing system***
  - governance model is expressed using policies
  - policies are bound to business goals

- Self-governance depends on ***self-knowledge***
  - model the capabilities of and constraints placed on the system, as a function of context

- ***Closed control loop*** enables the system to
  - *sense* changes in itself and its environment
  - *analyzes* changes to ensure that business goals are being met
  - *execute* changes to protect ***business goals***

Understanding the Environment



And Adapt Accordingly

Key Technologies

Hey Rocky, watch me pull a rabbit out of my hat!

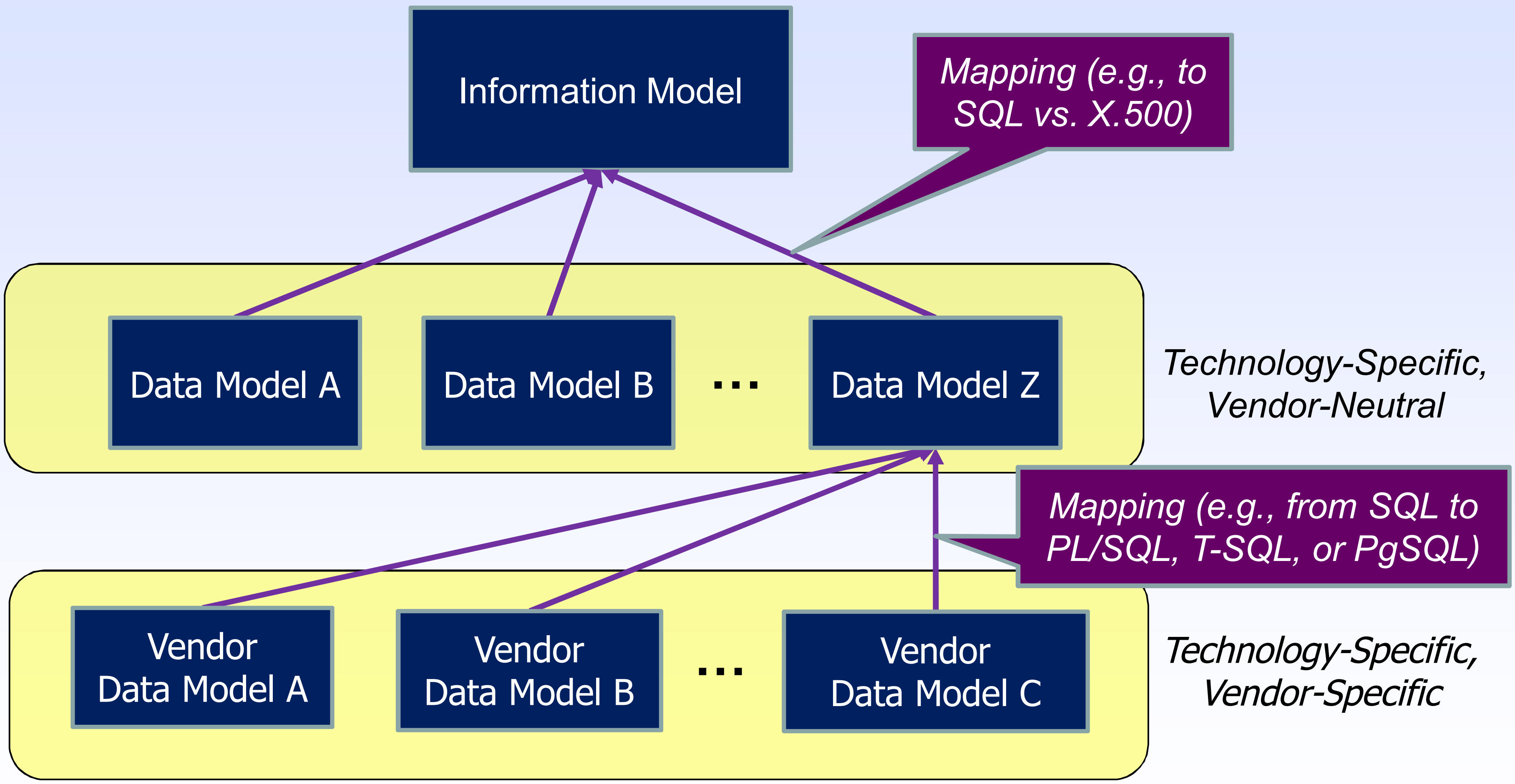
Again? That trick never works!

Note: this section is based on my autonomic research, and is described by a number of conference and journal publications and implementations. Let me know if you want access…

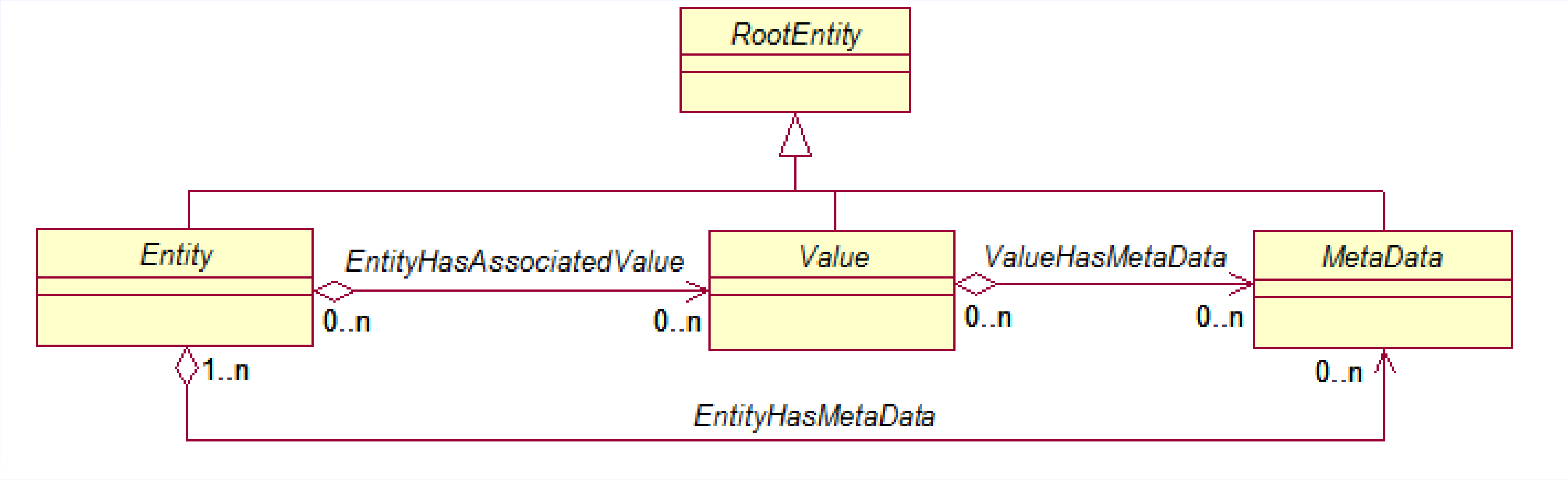
A Listing of Key Technologies

- Control Theory, Machine Learning and Inferencing
- Object-Oriented Information and Data Modeling
  - Mapping from an Information Model to different types of Data Models is crucial
- Policy-based, Context-aware Management
  - Event-condition-action, goal, and utility function policy rules all have their place
  - Using context to select policy is a powerful way to create adaptive behavior
- Ontology and Knowledge Engineering
  - Semantic relatedness using linguistics, pattern matching, and other methods
- Metadata-driven Adaptive Behavior
  - Crucial to changing behavior without having to regenerate code

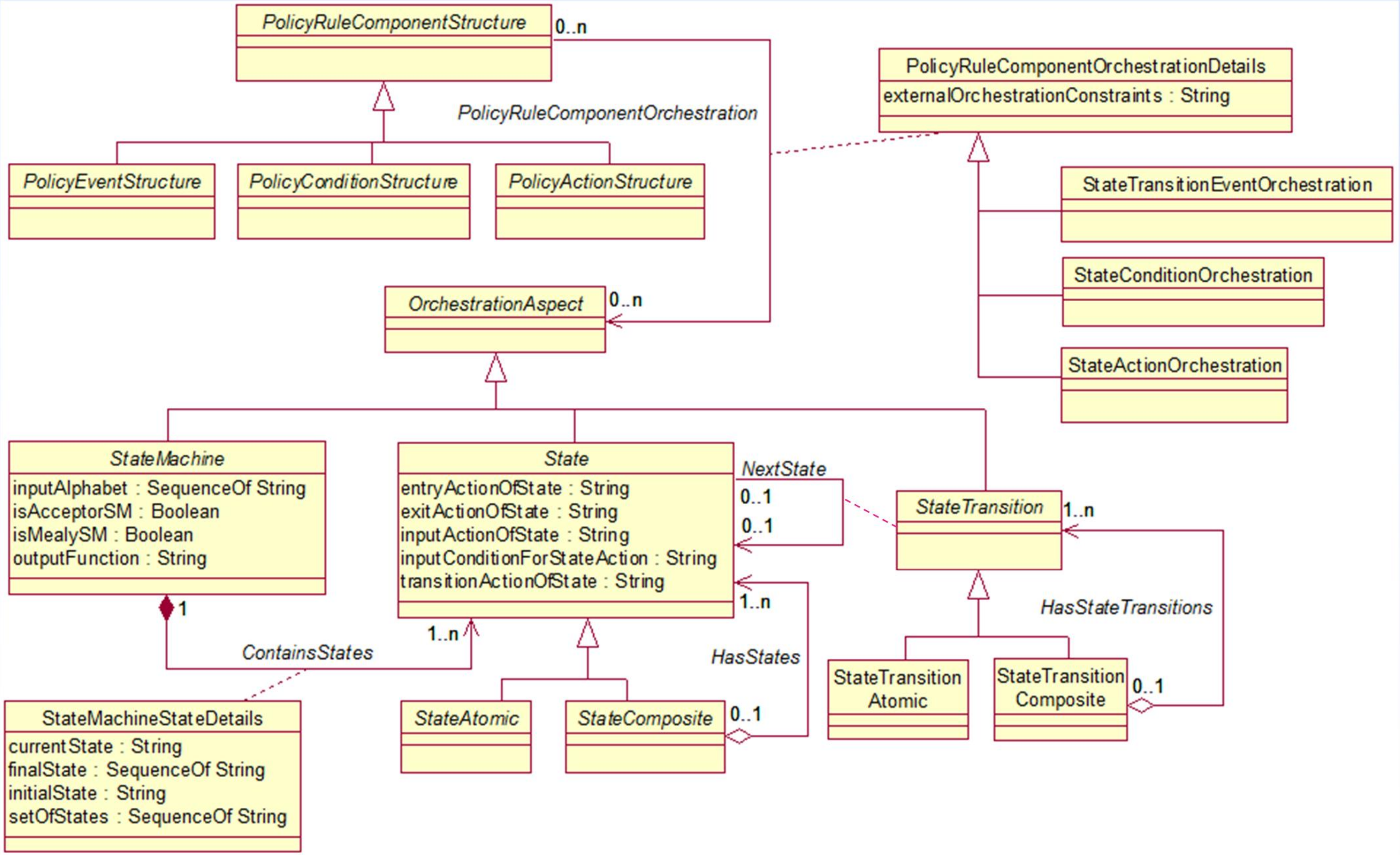
Modeling Terminology Illustrated



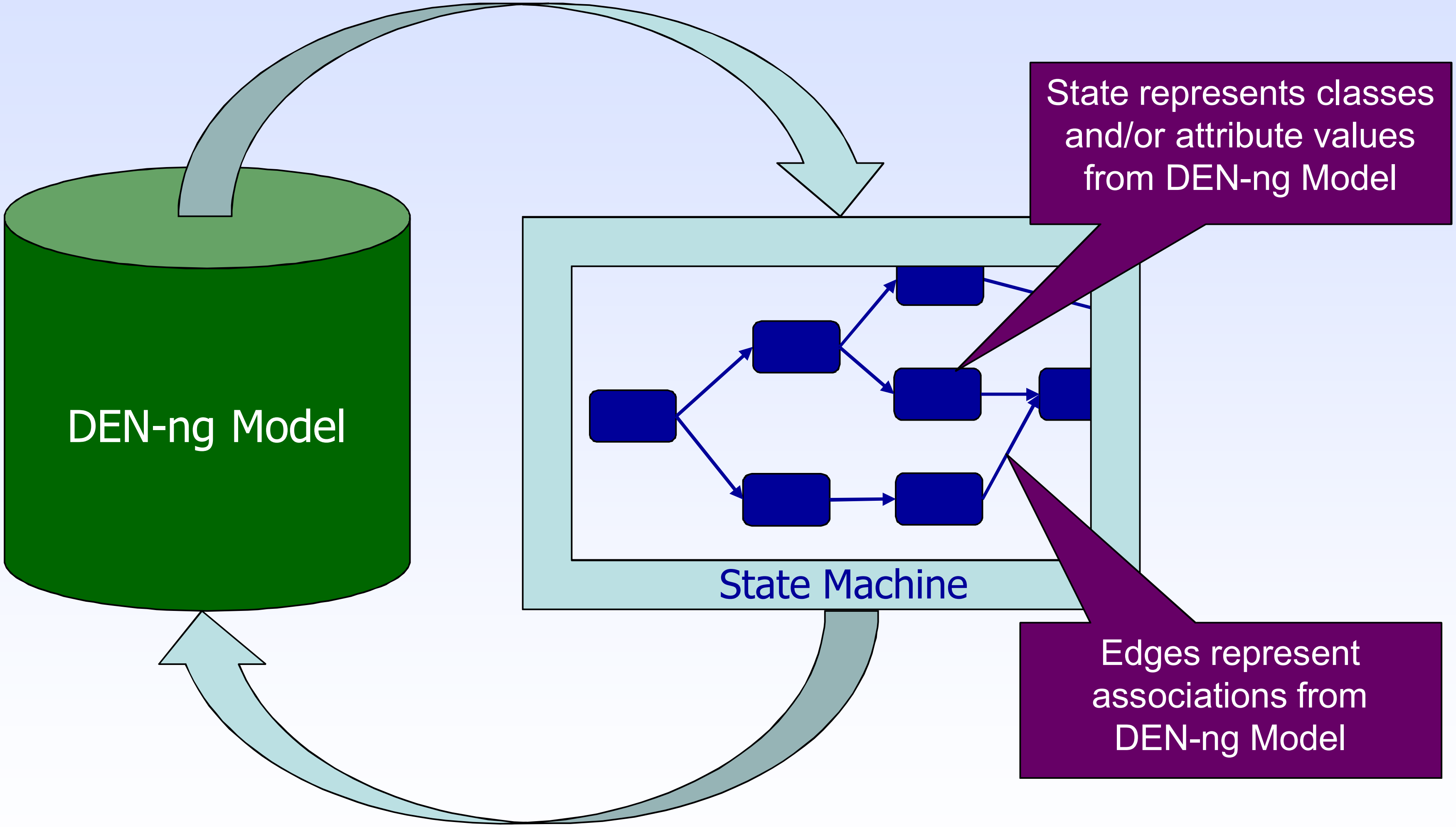
DEN-ng Supports Advanced Modeling



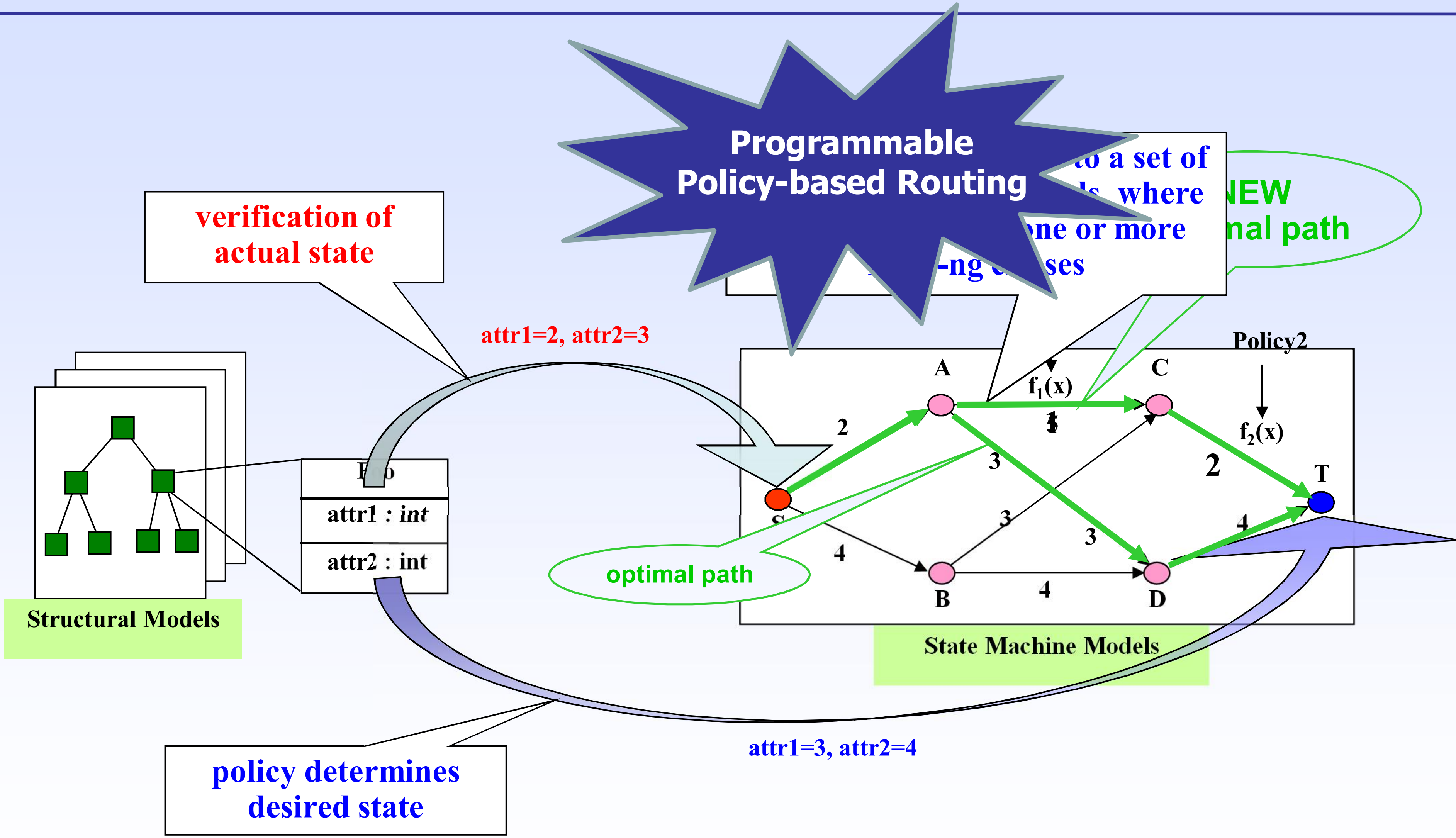
Simplified PolicyRule – State Interaction



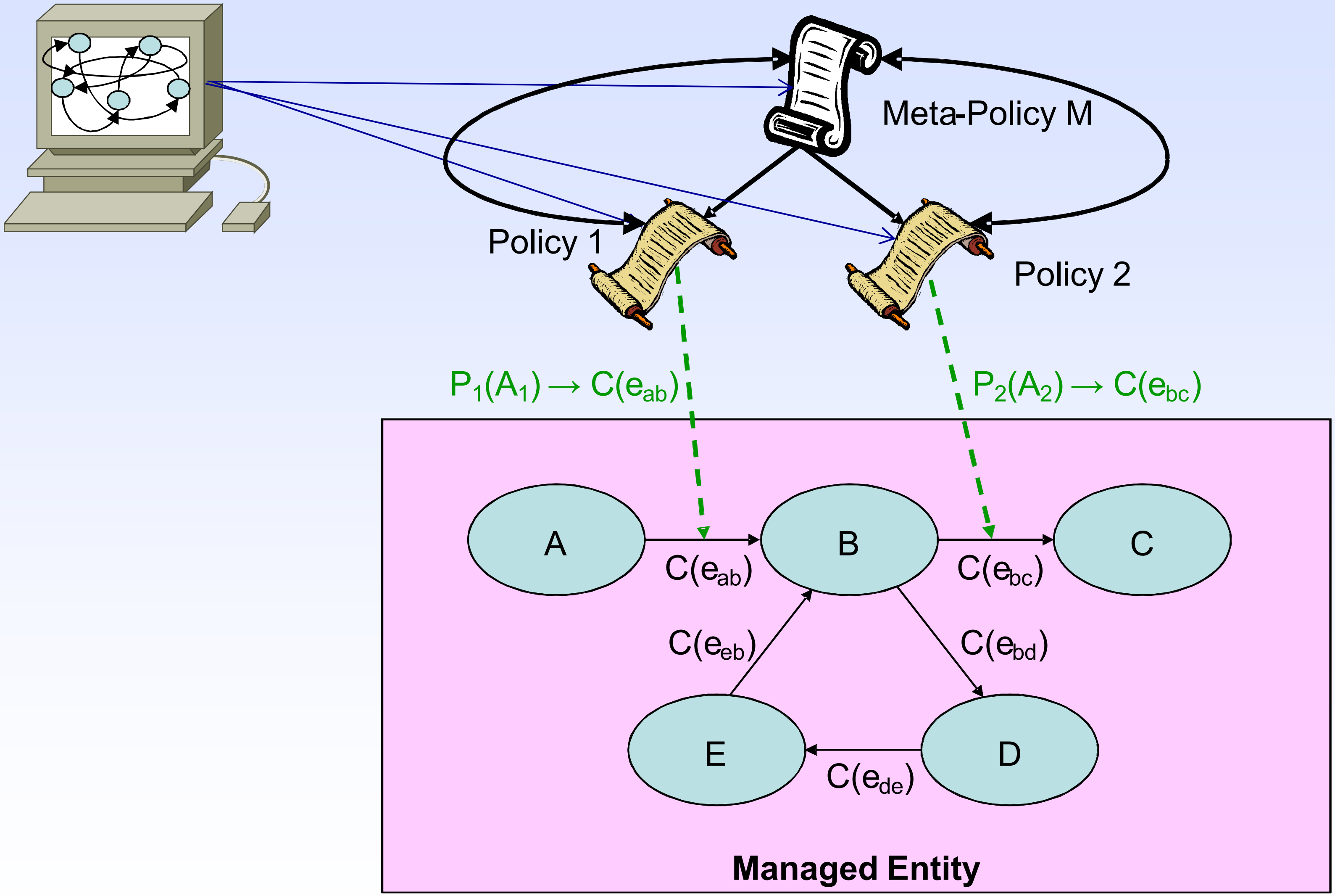
State-Driven Behavioral Orchestration



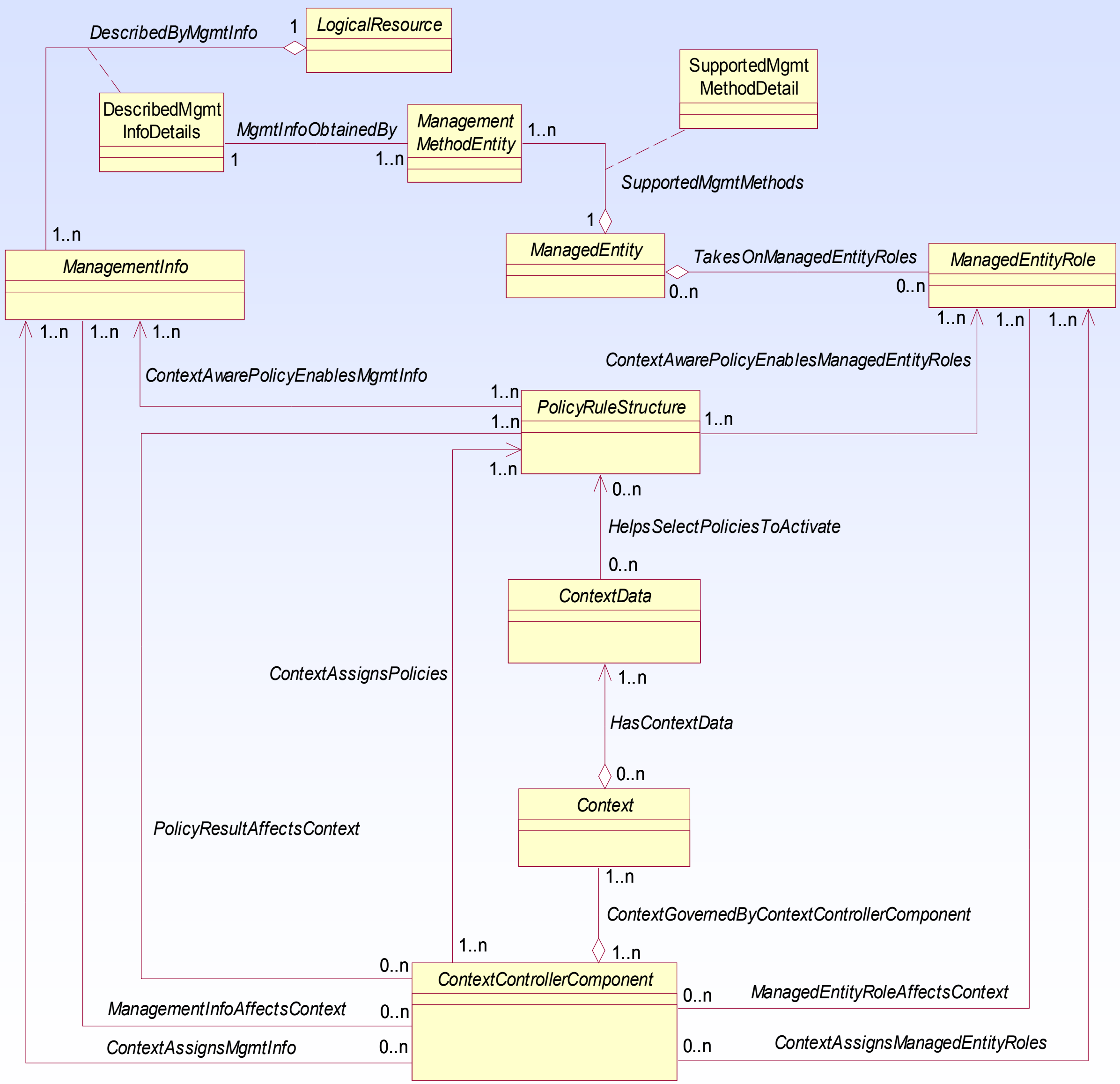
Policy-driven Behavior Orchestration (2)



Policy-Based Orchestration

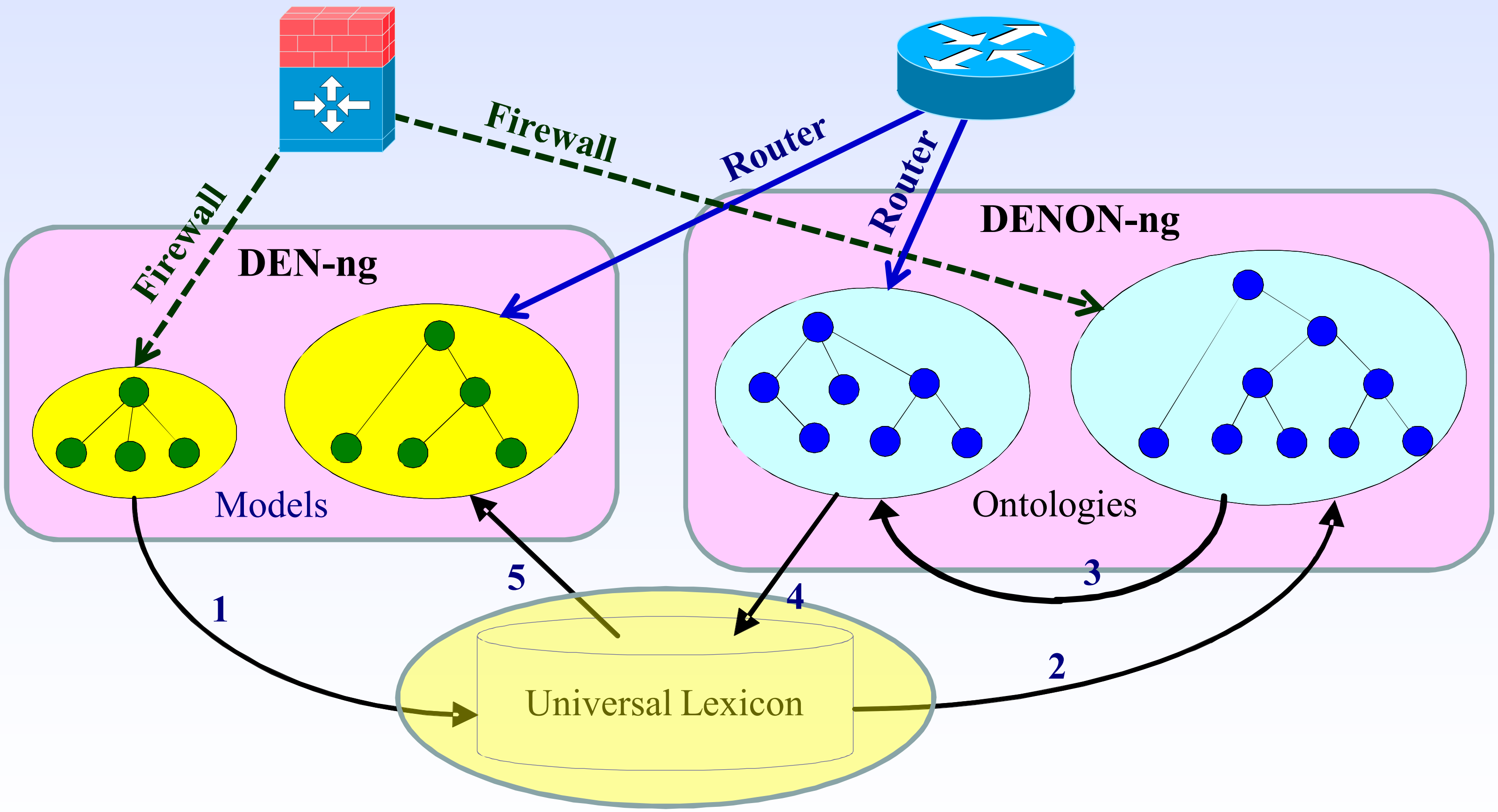


Situatedness



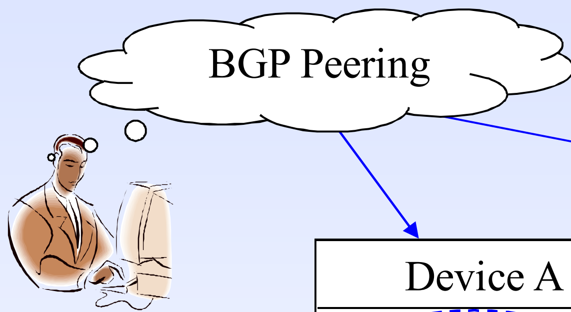
Information Integration

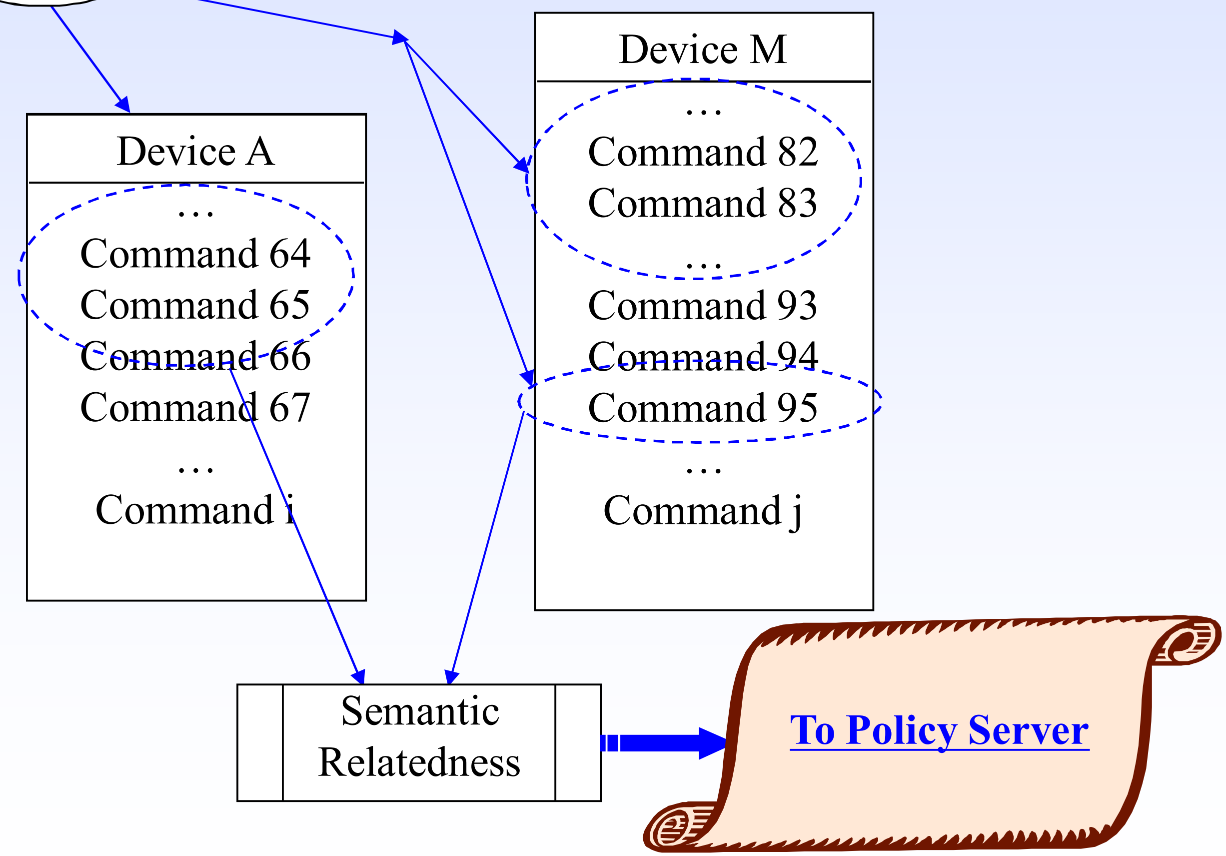
Which firewall commands are most similar to which router commands?



Ontology-Based Command Mapping

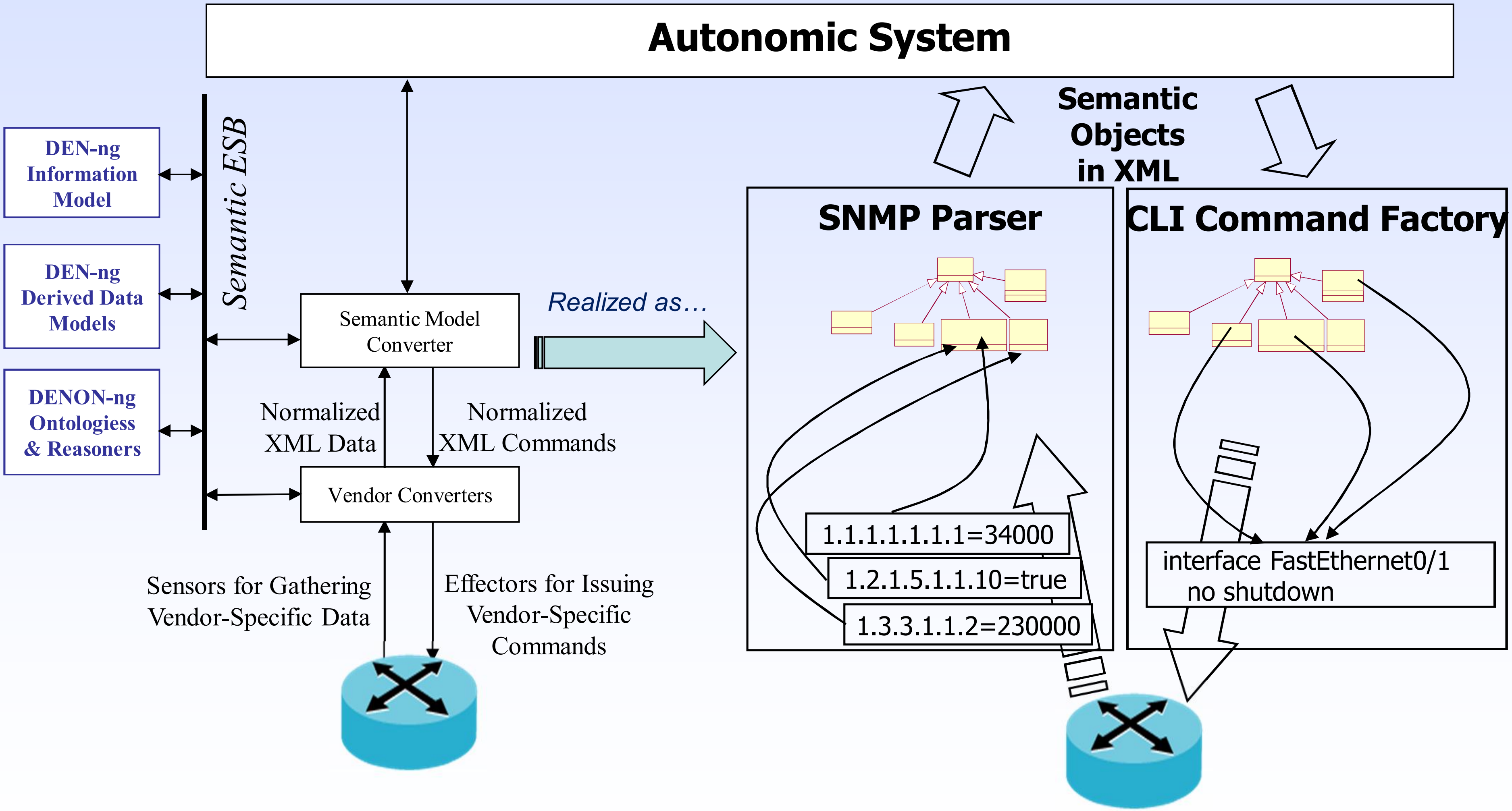
Mapping a High-Level Function to Different Command Sets in Different Devices



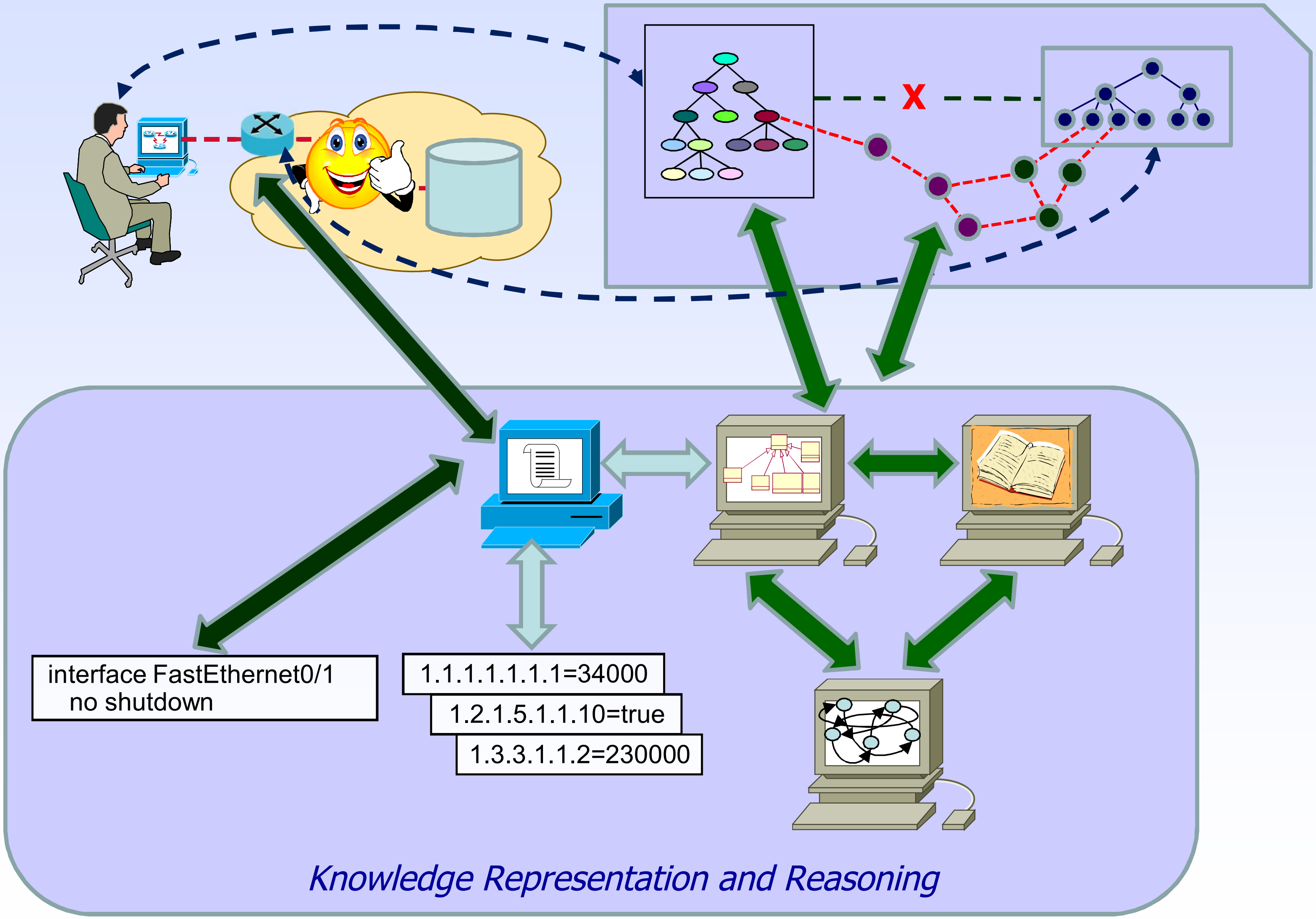


- Infer from DEN-ng Info/data model
- Construct concepts, relations, and FOL for ontological reasoning

MBTL Using CLI and SNMP



Novel Semantic Reasoning



Exemplar Research and Applications

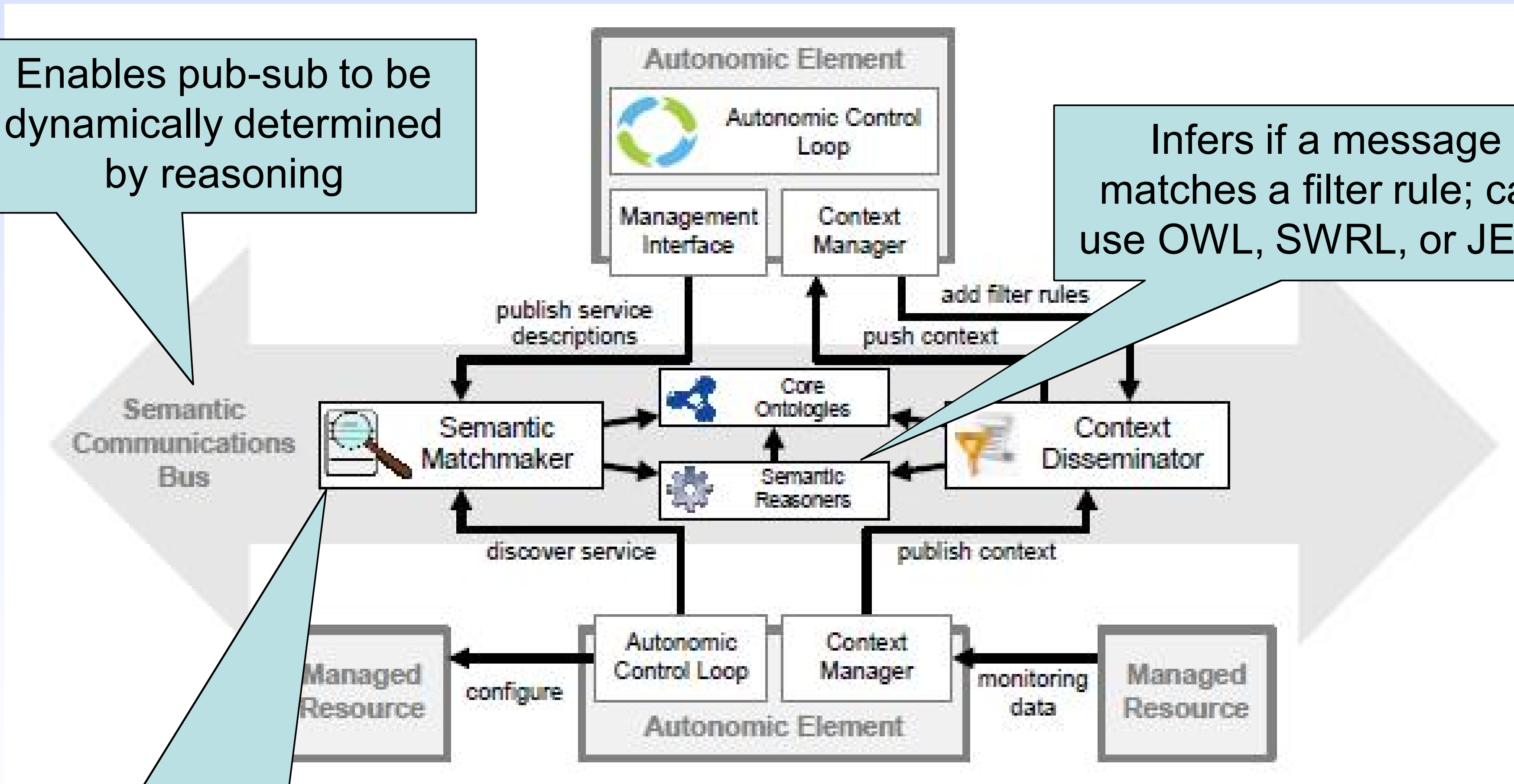
The Evolution of Management

- The element-based network management era is over!
  - *Converged* services require *converged* management
- Network management will *evolve*
  - From its current focus on *device configuration*
  - To become *service-oriented*
- Innovations are mandated
  - ITIL and eTOM were a good start…
  - …but they are collections of *best practices, NOT specifications*
  - SOA is interesting, but the foci should be:
  - (1) how to enable business needs to *drive* IT services
  - (2) How to *automate* business processes

Semantic Communications Bus

Enables pub-sub to be dynamically determined by reasoning

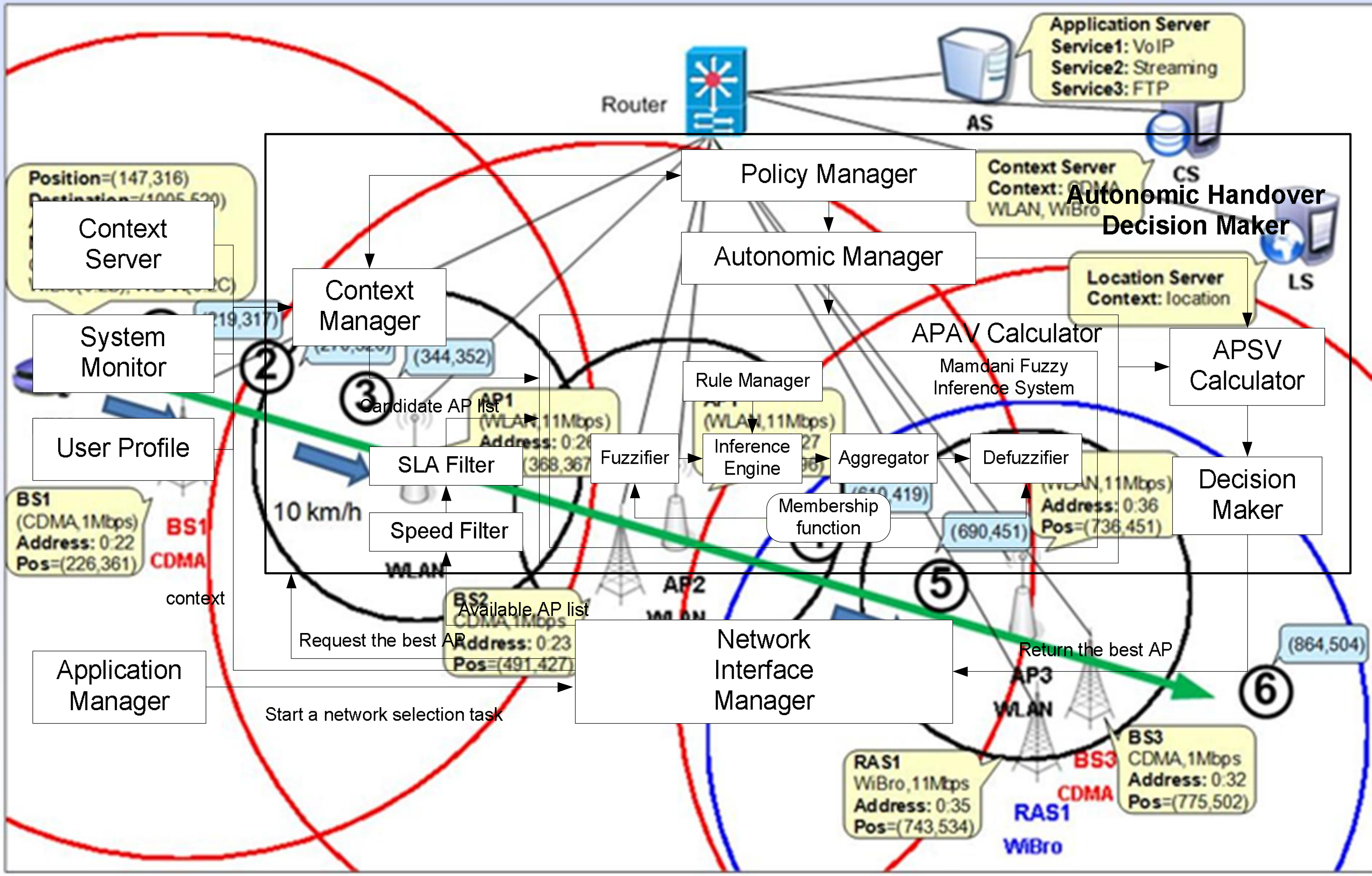
Infers if a message matches a filter rule; can use OWL, SWRL, or JENA



Maps offered service descriptions to requested needs

Research done in Univ of Gent

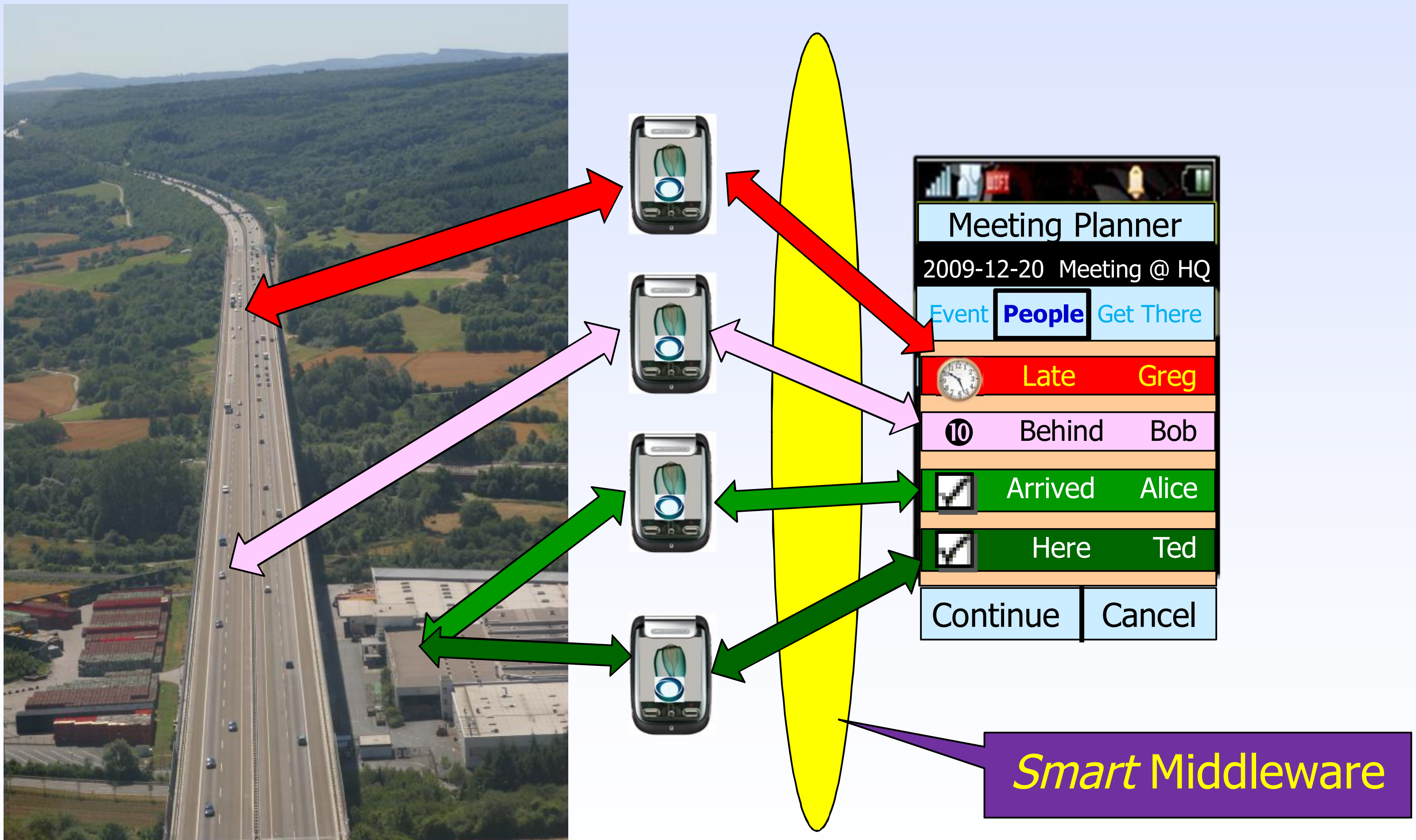
Autonomic Personalized Handover Decisions



Research done in POSTECH

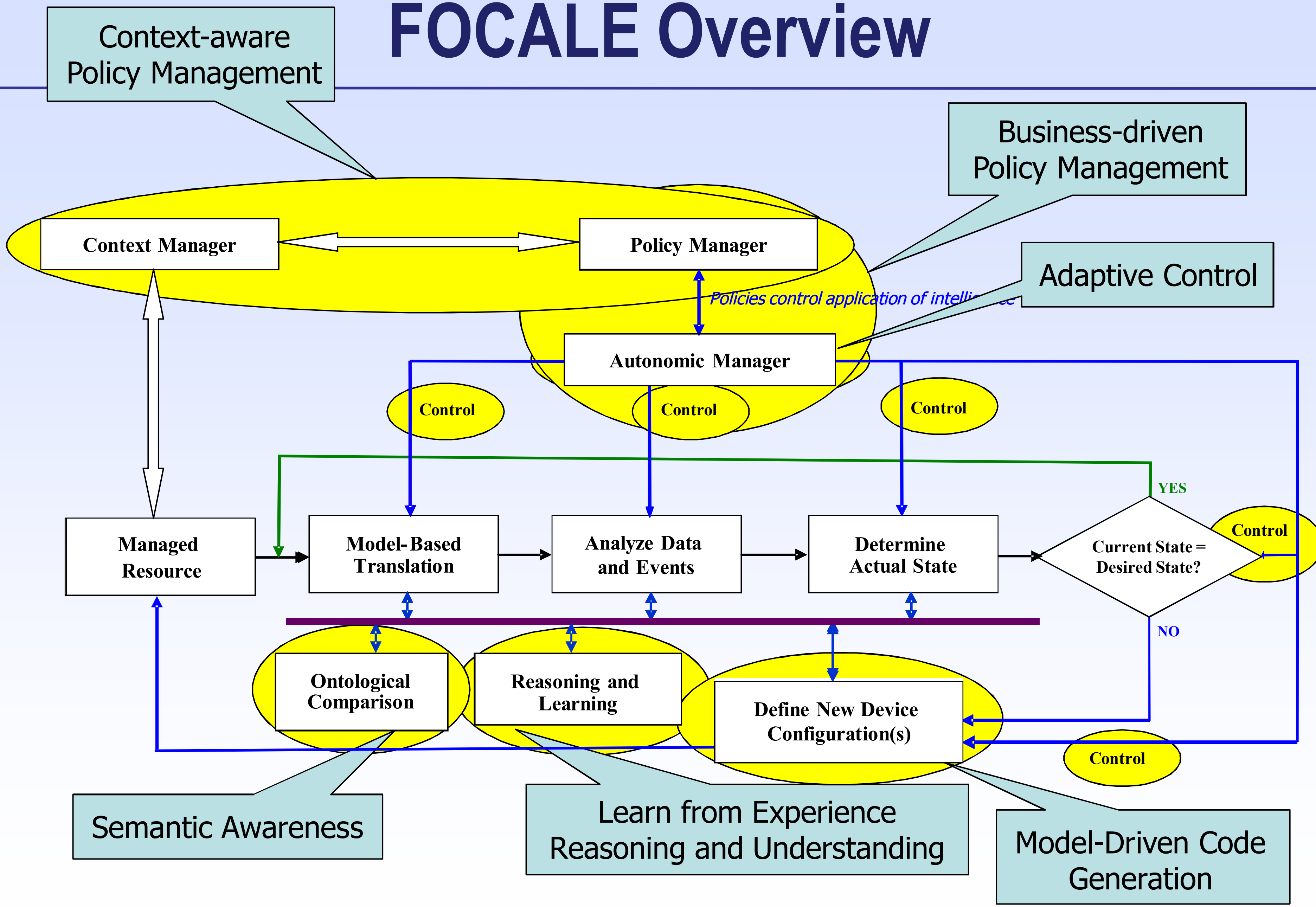
Ubiquitous Smart Meeting Assistance

It's 5 minutes before the agreed upon luncheon – where is everybody?

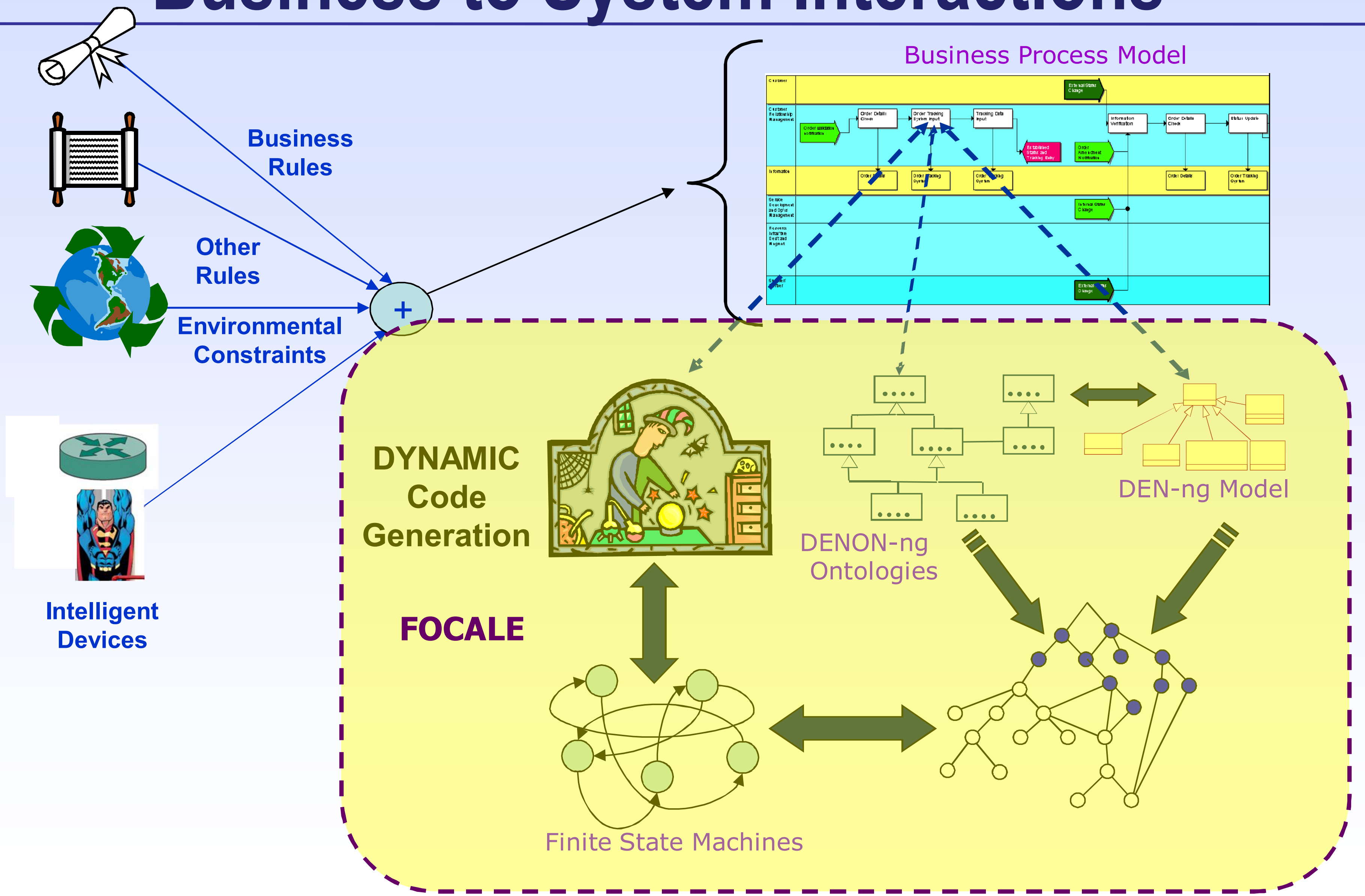


Prototype done in a NEM

FOCALE Overview



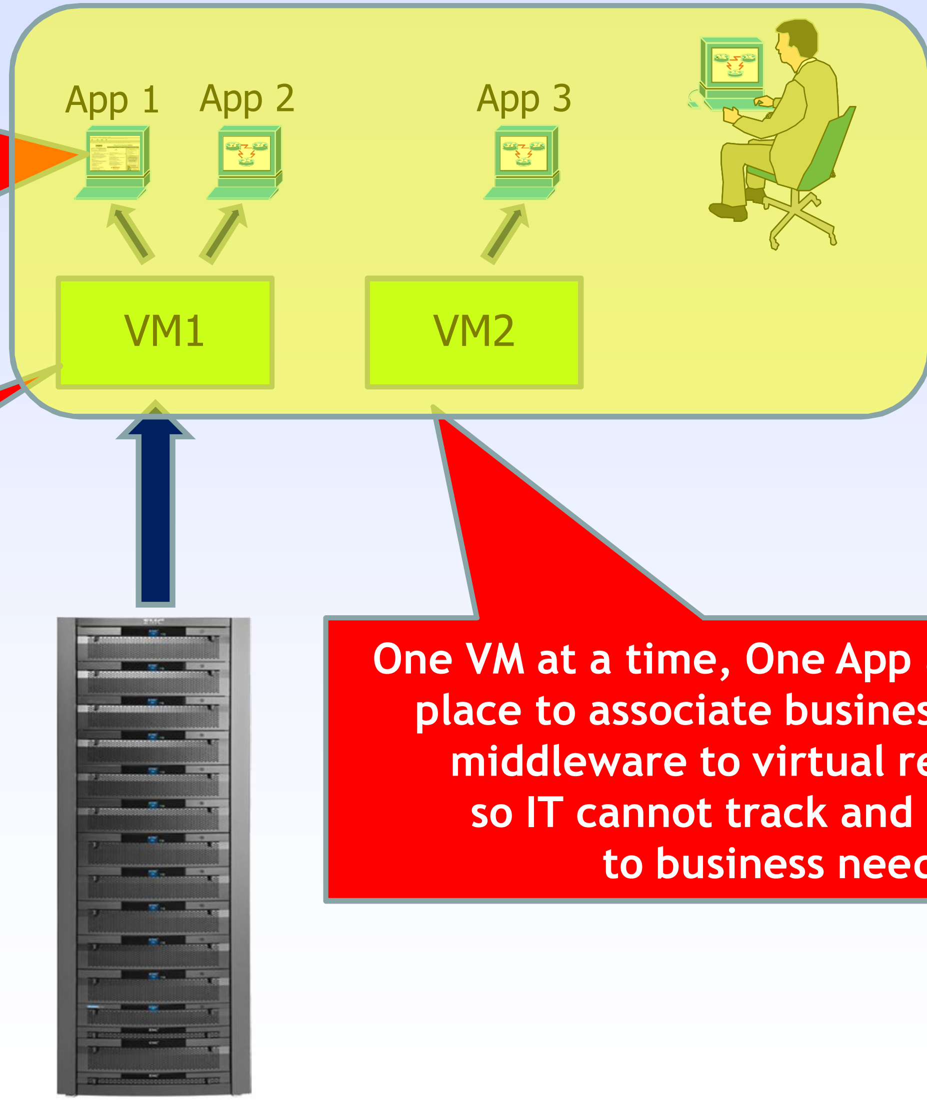
Business to System Interactions



The Next Generation of Management Applications from Huawei

Existing Application Infrastructure

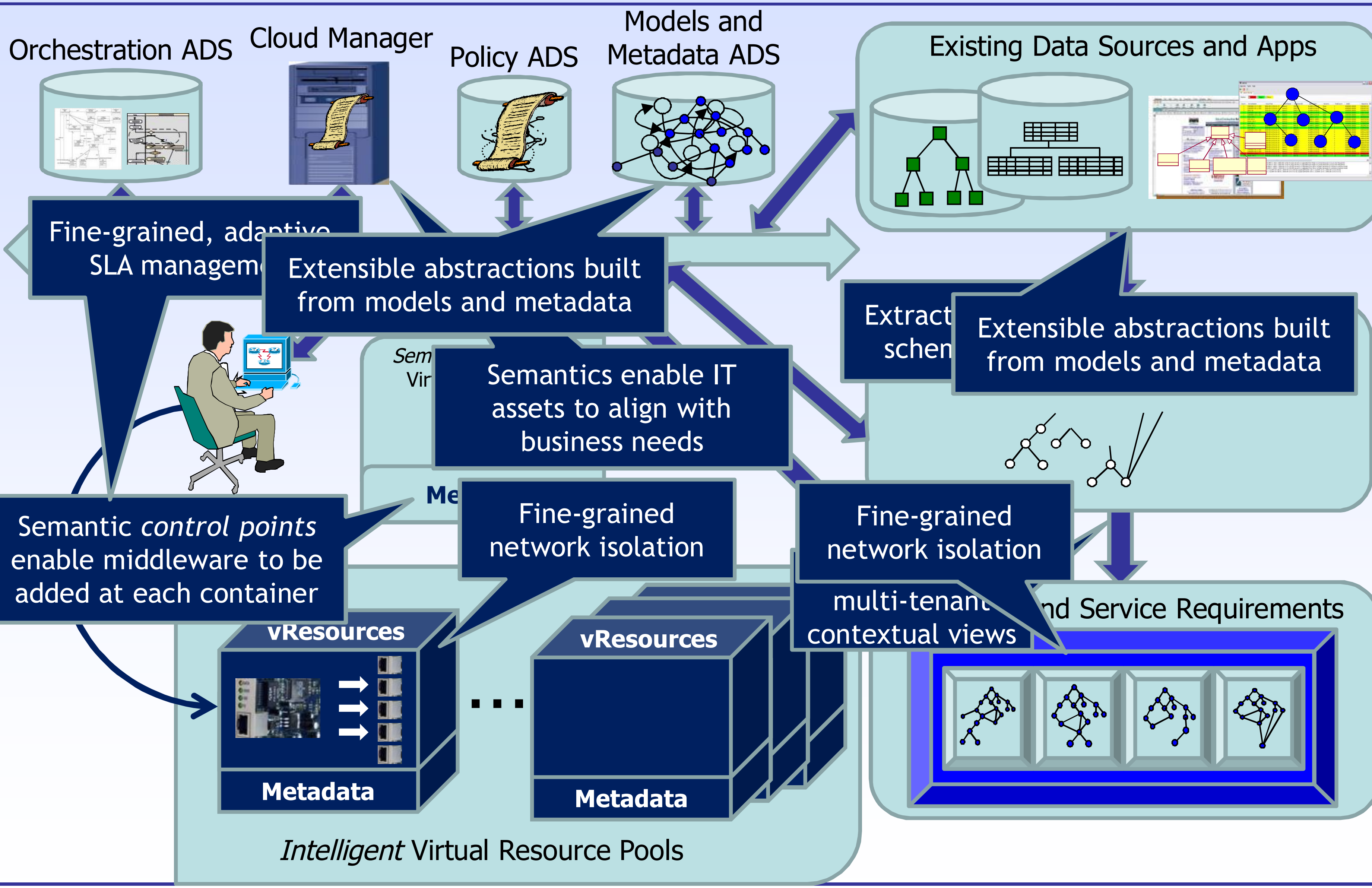
Lack of suitable abstractions require additional and complex middleware for a given application; automation cannot be fine-grained



Lack of suitable abstractions prevent choosing the best virtual resources for a given application; policies are limited to being applied at the container level

One VM at a time, One App at a time. No place to associate business logic and middleware to virtual resources, so IT cannot track and respond to business needs

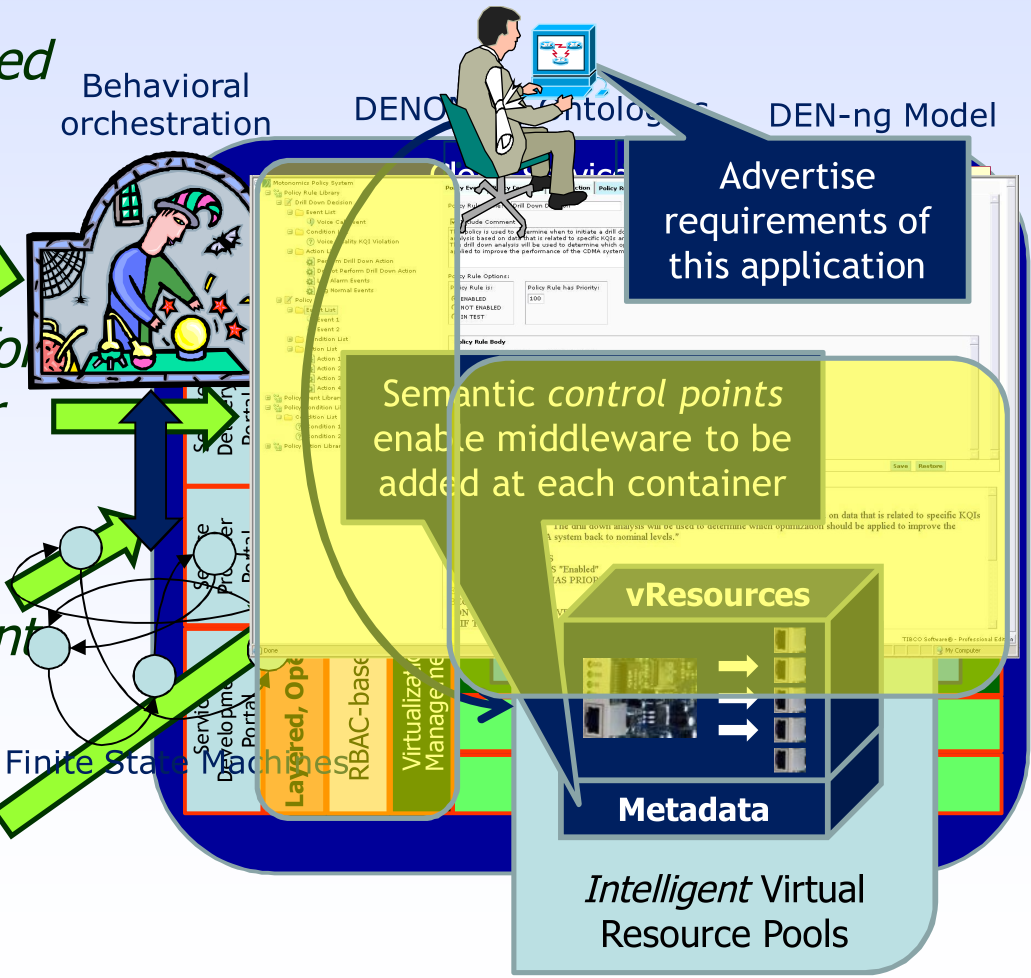
Semantic Orchestration



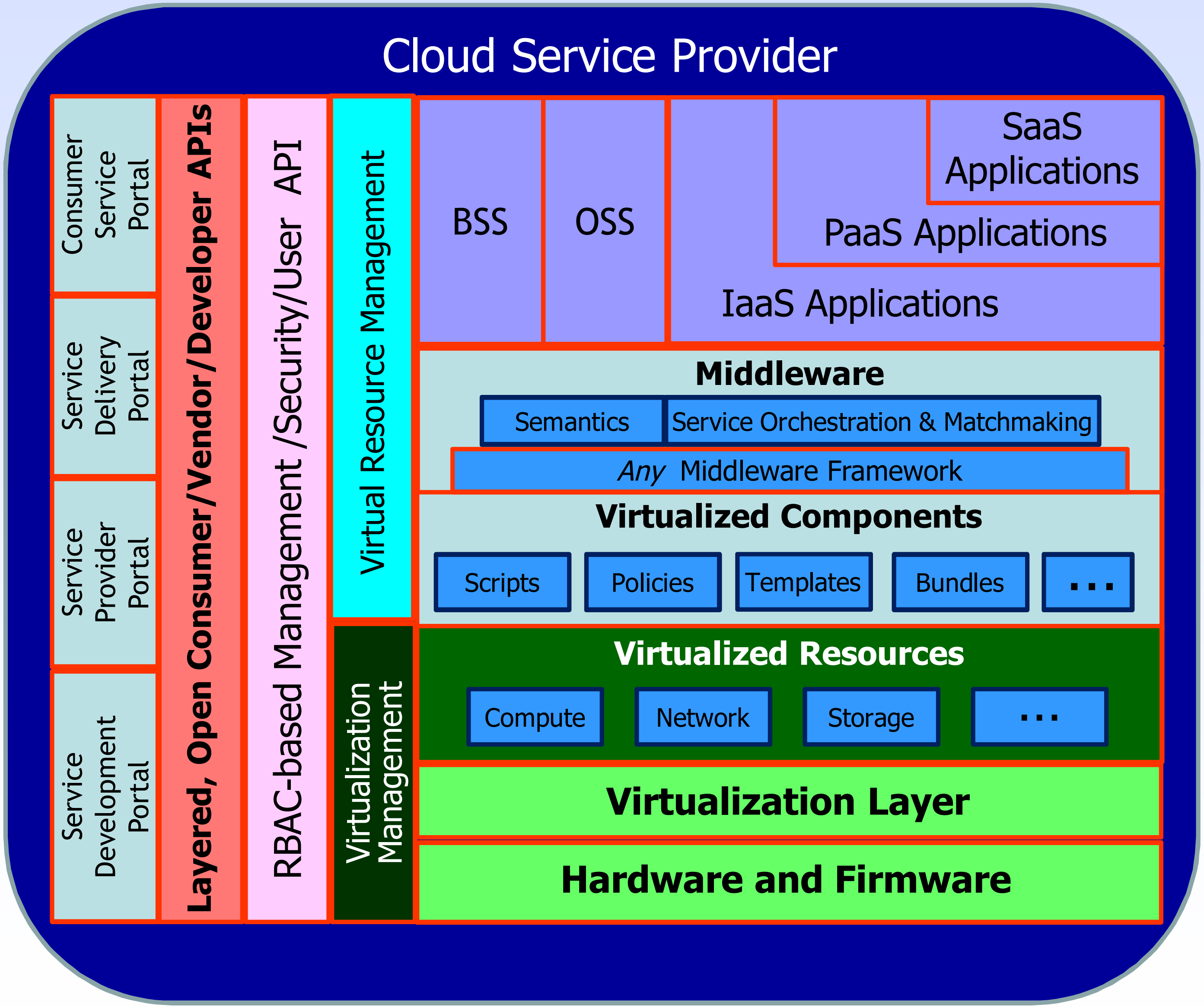
Intelligent Network Management

Most cloud computing environments have limited support for managing physical network resources

- *Integrate physical and cloud-based network and applications management in a single framework*
- *Define a single policy language for managing all entities (physical or virtual, network or otherwise)*
- *Provide an extensible API and accompanying set of management abstractions for exposing the primitives*
- *Programmable virtual network devices*



Huawei High-Level Architecture Picture



Metadata-driven Architecture

- An architecture that dynamically adapts to change
  - Not *new*, just a *better implementation***
  - DEN-ng metadata model *describes the characteristics and behavior of all managed entities (classes, relationships, constraints, behaviors) as objects*
  - This enables the *object model(s)* to be *interpreted at runtime*
    - When metadata changes, the system immediately reflects those changes *without requiring code changes*
    - Applies to business rules and new features (e.g., new devices)
    - Objects have states and respond to events by changing state; the object model defines the objects, their states, the events, and the conditions under which an object changes state
    - Object model can be stored either in XML files or in a database


The Quest for the Holy Grail

Summary (1)

Scalable network management for converged physical, logical, and virtual resources remains an elusive challenge

Summary (2)

A single über-language is a myth; we need to embrace standards as well as proprietary data models via *mappings*

Summary (3)

Integrating ***Knowledge*** from
Models and Ontologies shows promise

Summary (4)

Research is making progress. Enjoy the conference!

Questions?

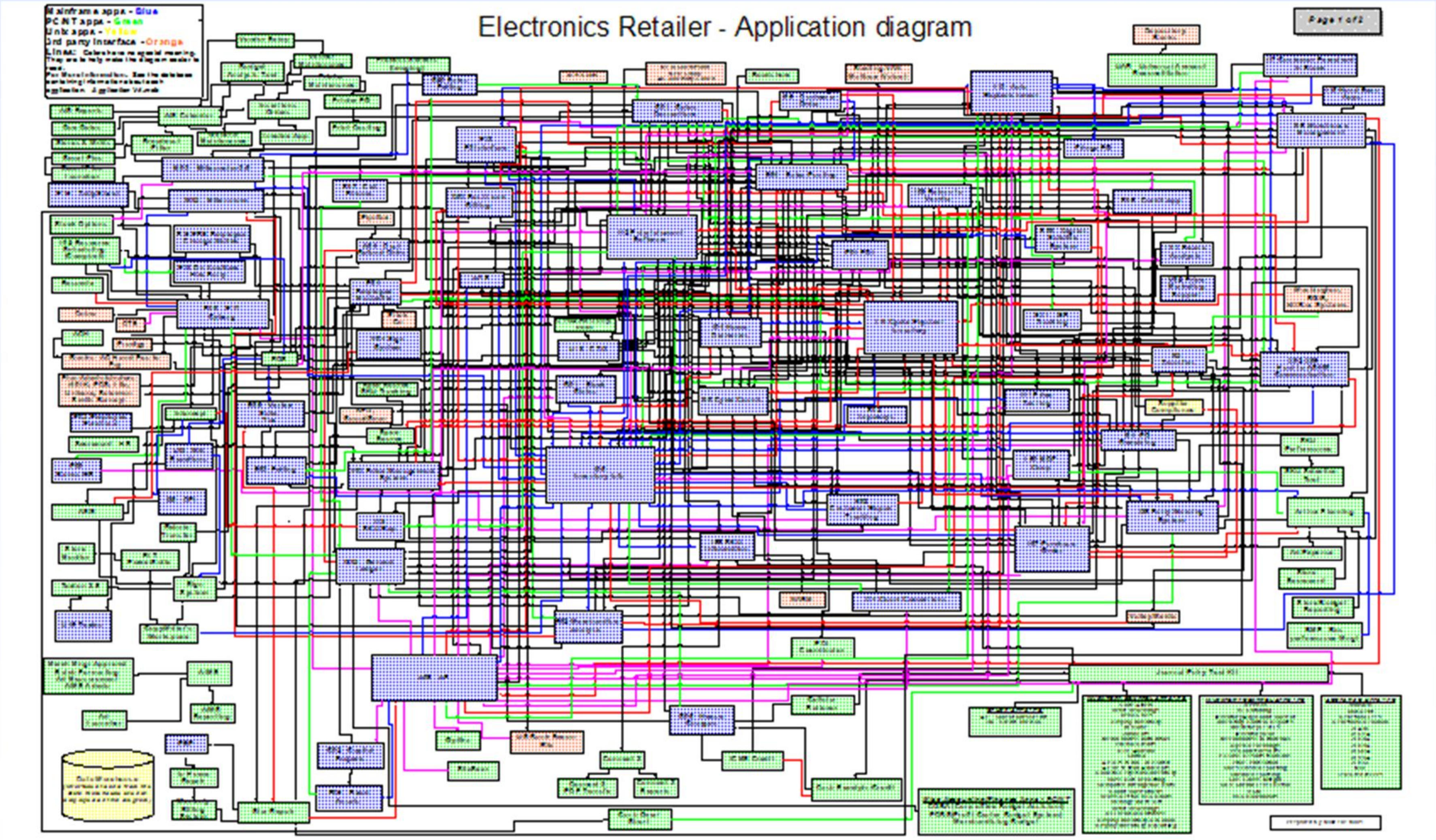
Questions?

"Create like a god. Command like a king. Work like a slave"

- Constantin Brancusi

Appendix: Motivation: Technical Factors

I/T is Becoming Too Complex!

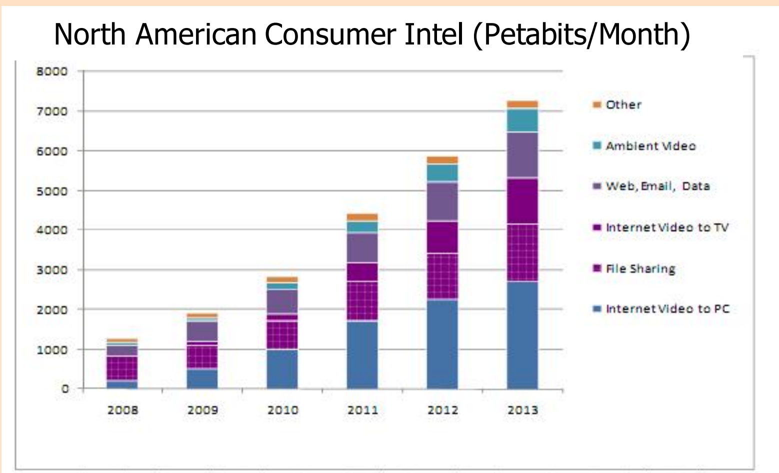


Appendix:
Motivation: Economic Factors

Exponential Data Growth

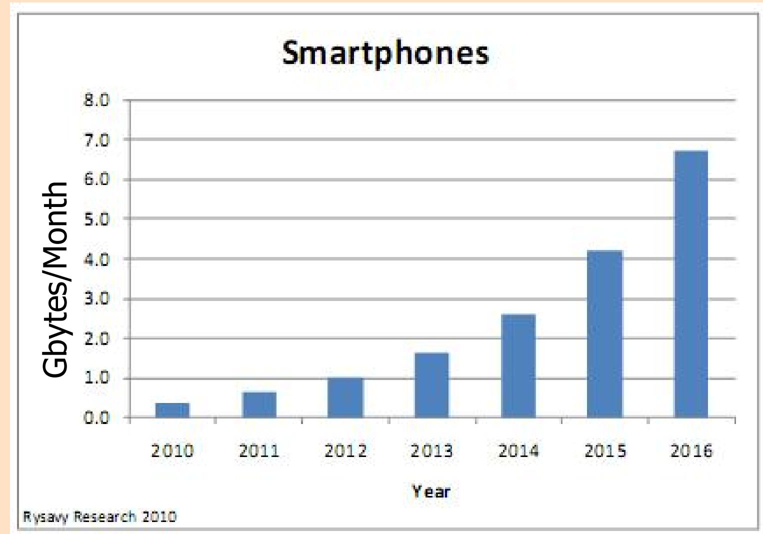
Data Growth will Outpace Network Capability

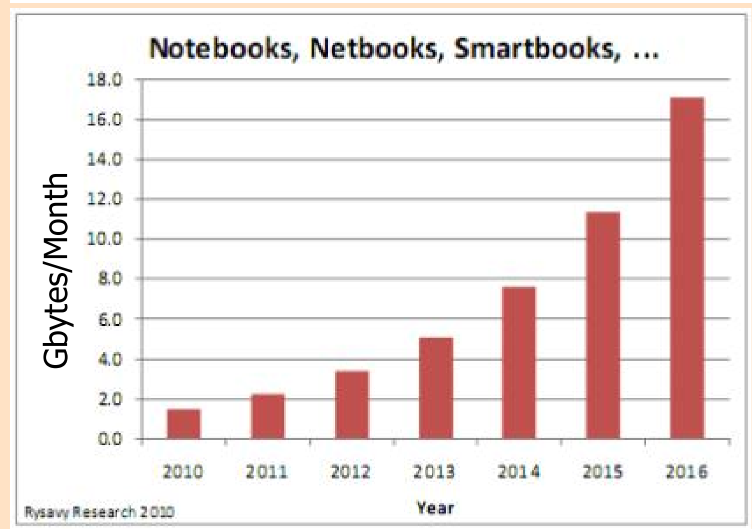
Fixed



Source: Cisco Visual Networking Index; Morgan Stanley Research estimates. Note: Data is for North America, limited to non-mobile consumer usage
Adapted from Morgan Stanley Research, U.S. Cable, Satellite, Telecom 3Q09 Outlook, Oct. 21, 2009 at 17.

Mobile

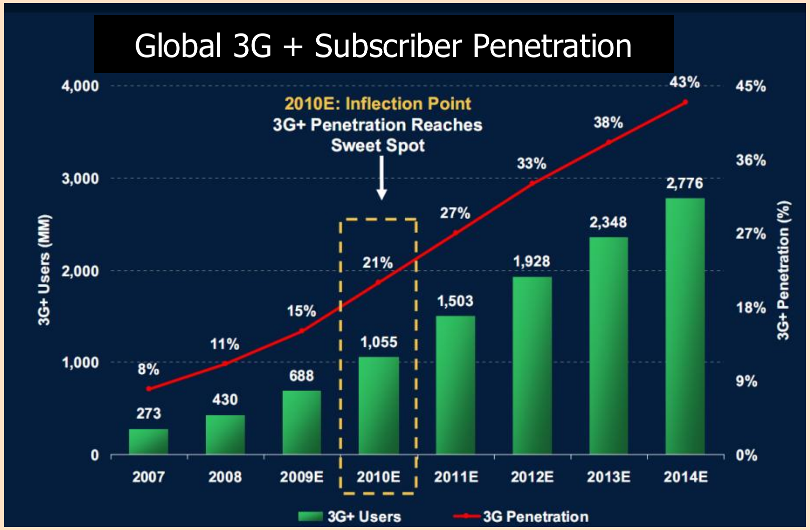




Subscriber Growth

Number of Fixed and Mobile Subscribers is Growing

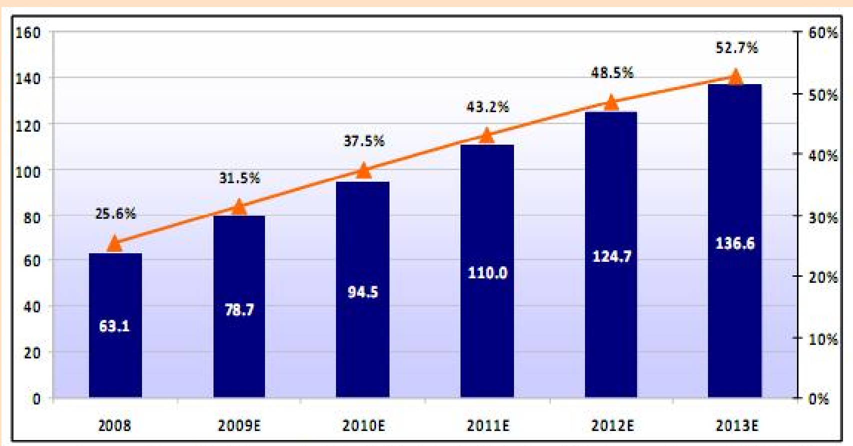
Mobile



Source: Morgan Stanley, "Mobile Internet"

Fixed

US Broadband Subscriber Growth in Millions



Source: Average of analyst data provided to CITI, Jupiter U.S. Wireless Data Access Forecast 2008-2013, and population from U.S. Census.[239]

Average Revenue Per User (ARPU)

ARPU on Fixed and Mobile Networks is Relatively Flat

Mobile

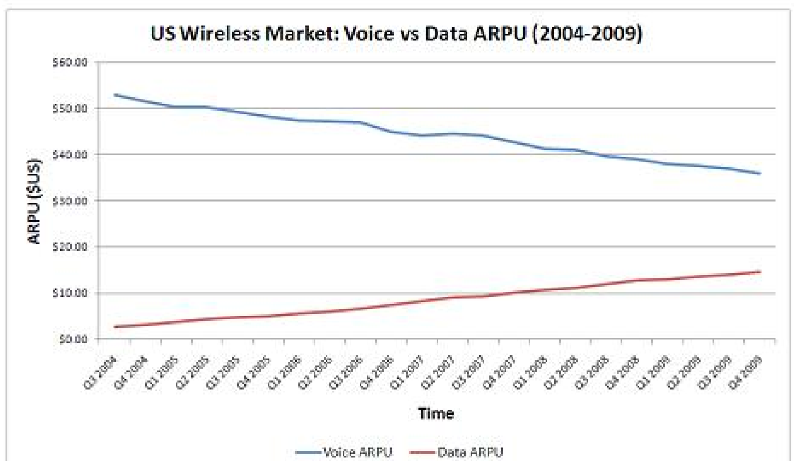
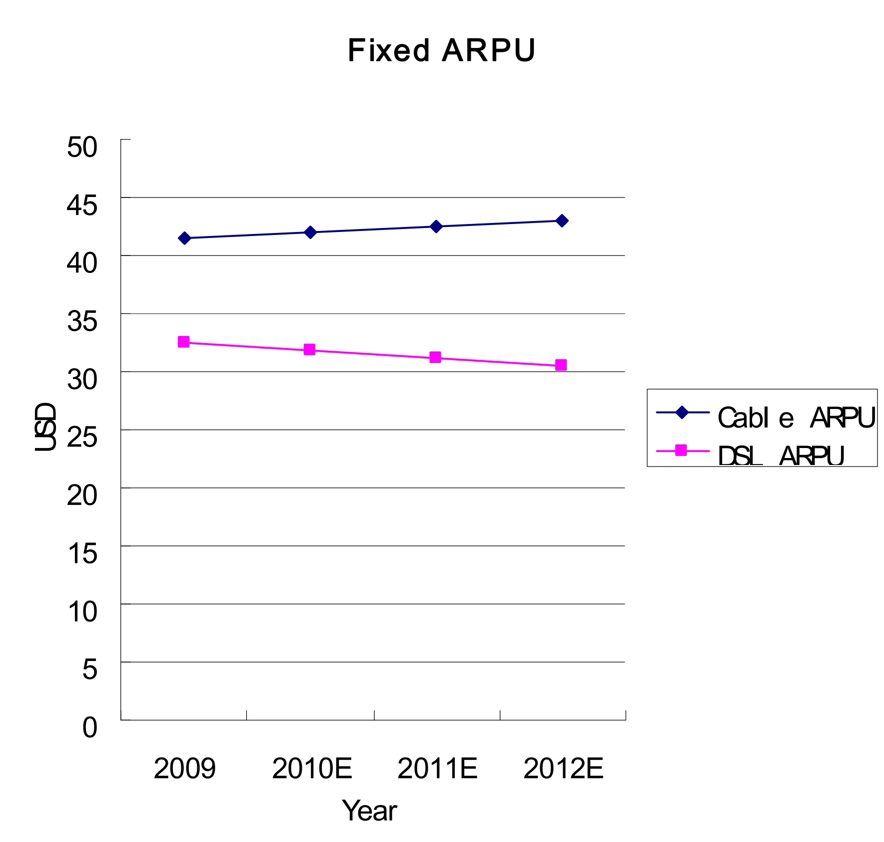


Figure 3 - US Wireless Market - Voice vs Data ARPU (2004-2009)[10]

Source: Sandvine, "Mobile Internet Phenomenia Report"

Fixed



Source: Columbia Institute for Tele-Information, "Broadband in America"

Appendix:
Motivation: Societal Factors

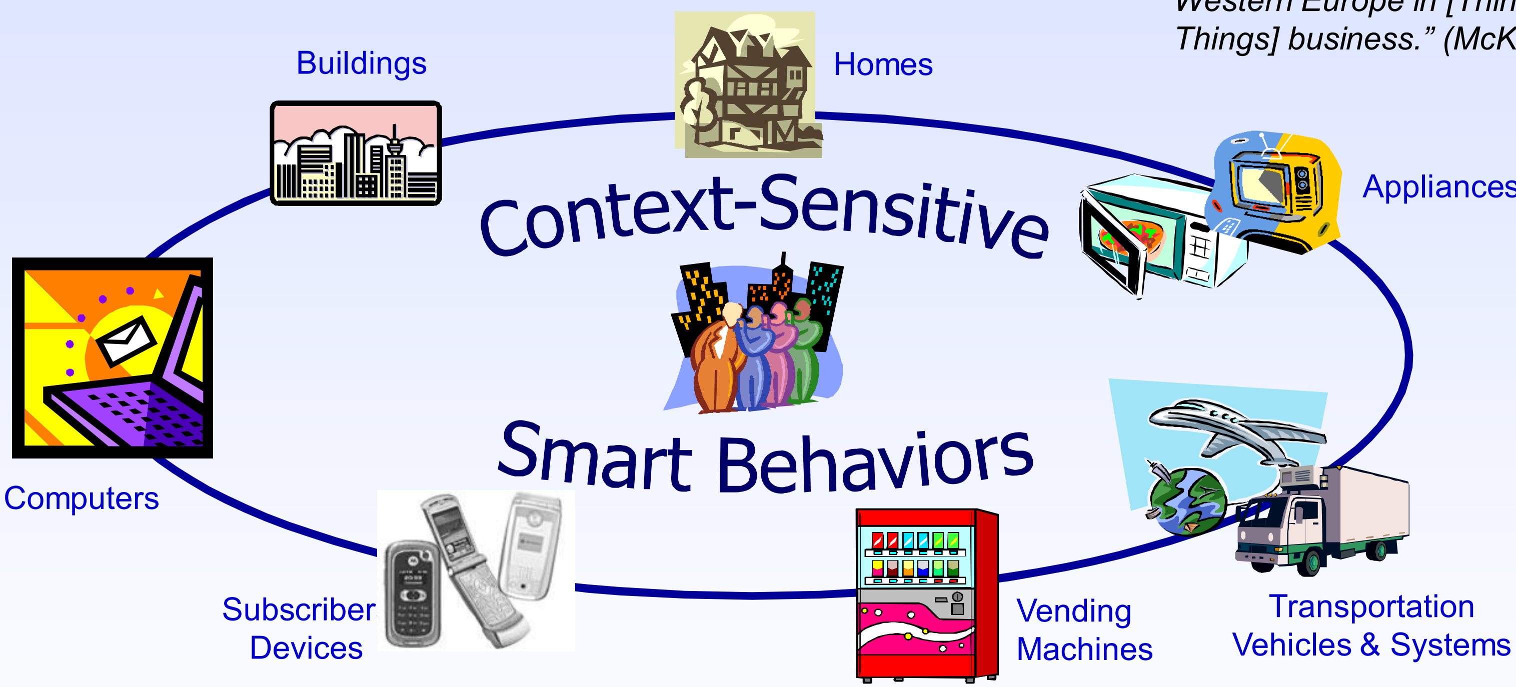
“Digital Natives”

- “Digital natives” (Mark Prensky) have spent their entire lives surrounded by and using computers, videogames, digital music players, video cams, cell phones and all the other toys and tools of the digital age
  - Born roughly between 1980 and 1994 (“Y Generation”)
  - Characterized by their familiarity with and reliance on ICT
  - Are adept at processing information rapidly
  - Like quick, non-linear access to information
- It is now clear that as a result of this ubiquitous environment and the sheer volume of their interaction with it, today’s students *think and process information fundamentally differently* from their predecessors
- **Today’s users *expect* intelligence!**

The Killer App is Intelligence

People to People → People to Things → Things to Things

" $100 billion in combined revenue seen by 2010 for US, Japan and Western Europe in [Things-to-Things] business." (McKinsey & Co.)



End Users Require:

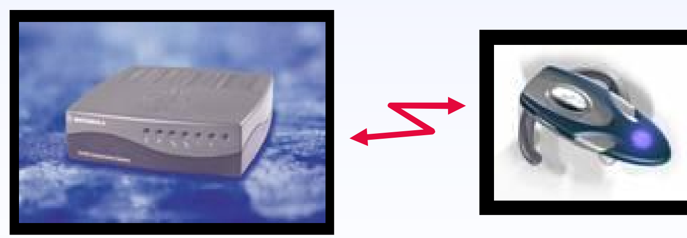
- Multiple Handsets
- "Always On" Connectivity – Anywhere Anytime
- Converged Services Available via Multiple Form of Access

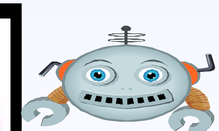
Ubiquitous Communications

People to People

People to Things

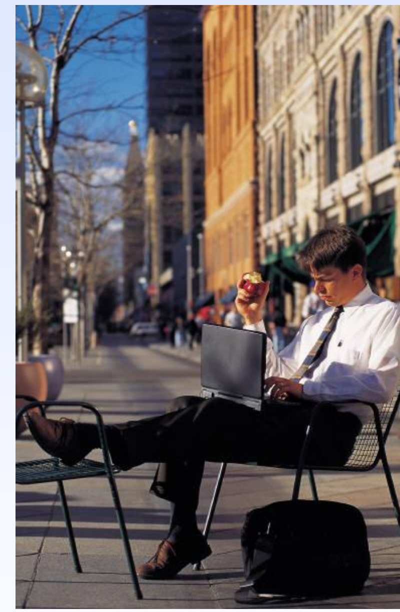
Things to People

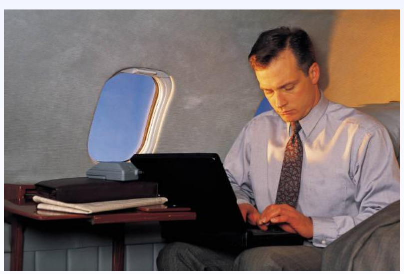


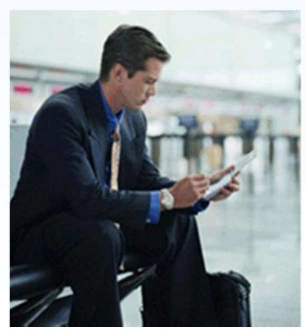


Things to Things

The Evolving "Global Workplace"







Appendix: Motivation: Wisdom

Enterprise Trends (1)

- **Security**
  - Enterprise mobility, mobile devices, cloud computing, new technologies, virtualization, and mobile apps are presenting new security and compliance challenges
- **Data Management**
  - Increasing volumes, more emphasis on *unstructured data*
- **Cloud Services**
  - Requires robust and interoperable APIs; promise of reduced costs and ROI will increase drive to cloud
- **Business Intelligence and Analytics**
  - Enables improved decision-making, identifies new business opportunities, maximizes cost savings and improves efficiencies
- **Enterprise Mobility**
  - Globalization and usage of mobile devices and apps offer the chance for increased productivity but have more security risks

Enterprise Trends (2)

- IT Management
  - Redeploy IT resources to improve IT department’s relevance; need for creating custom data apps to improve productivity
- Collaboration
  - Social networking, mobile devices and app usage is promoting collaboration and teamwork; rise of customer-centric GUIs
- Machine-Machine and Internet of Things
  - Embedded devices, customer touch-points and context-aware services can improve business processes and productivity
- SOA
  - Business rules processing and policy-based service orchestration will move to the mainstream
- Data Center Scalability
  - Hard for traditional data centers to scale and meet cost and resource budgets; this is driving cloud computing adoption

"Enterprise 2.0"

- "***Enterprise 2.0*** *is the use of emergent social software platforms within companies, or between companies and their partners or customers" – Prof. Andrew McAfee, Harvard*
  - The use of Web 2.0 technologies to streamline business processes while enhancing collaboration
  - People use social business tools instead of "legacy" communication tools
  - Information is accessed through a web of inter-connected applications, services and devices

IT Trends (1)

- Intranet Replaced by Social Net and Tools
  - Intranet only used for static templates and data; social business platforms provide crowdsourcing, following interests, polls, and other tools seamlessly integrated with smartphones
- Mobile Computing
  - Pervasive means of communication and use of personal apps
- Cloud Service SLAs
  - Pressure to move services to cloud, but worried about SLAs
- Private Clouds
  - Public Clouds lack maturity and security; private clouds and on-premise hosting will rise dramatically
- Modernization of Legacy Apps
  - Legacy apps have too much investment and are too critical to be replaced, but need incremental updating to increase usability and ROEI

IT Trends (2)

- Business Intelligence
  - Explosion of different types of data requires more sophisticated means for analyzing trends and relevance; link to mobile apps
- Multi-Tier Architecture
  - Move towards 3-tier app: app platform layer, middleware layer, and BI layer
- Recession
  - No increase in staff or budget, so IT needs smarter tools to make better decisions; automation even more important
- Agile Business Communication
  - Mobile apps and devices empower knowledge workers; LAN-centric monolithic apps will start being replaced

Telecom Trends (1)

- Managed Services
  - Businesses will increasingly focus on core competencies and outsource non-core tech functions
- Network Convergence
  - Any app on any device used any place over any medium
- Cloud Computing Embraced
  - Increasing demand for simple services and large outsourcing will drive carriers to offer cloud services
- Portals for Enabling Content
  - In order to avoid being marginalized as dumb pipes, SPs want to provide new content and “webify” their offerings
- Analytics
  - Avoiding customer churn and increasing customer loyalty can be better achieved by using customer analytics

Telecom Trends (2)

- All IP Backbone
  - Verizon will upgrade its backbone from 10 and 40 Gbps to 100 Gbps, which provides increased capacity as well as operational improvements resulting in faster activation of capacity; increasing dual-stack IPv6 support
- Next-Generation Services
  - Networks will be upgraded to emphasize cloud and video (e.g., cloud-based backup and Verizon's Flex View)
- Personalized Services
  - Consumers are demanding context-aware services that adjust according to the task being performed, including metered services instead of traditional Gold/Silver/Bronze static services

Appendix: What Went Wrong?

The Problem – Managing *Complexity*

- **The complexity of system design and management keeps increasing**
  - Stovepipe systems: best-of-breed functionality but integration nightmares
  - Increased technology overwhelms users and administrators
    - Different devices have different programming models and interaction models
    - Different management tasks and integration types require different skill levels
- **The complexity of business is also increasing**
  - People are demanding a pervasive presence
  - Many types of businesses LOSE MONEY if they can't react fast enough
  - Varieties of threats, problems, and non-optimized behavior keeps increasing
- **Behavioral complexity is also increasing**
  - Everything is interconnected, requiring different policies and functions
  - Too complex to predict, needs too high a skill level, not enough people!
- ***These result in…***

Some Effects of Complexity

- Expensive
  - Cost of management by administrators is increasing (CAPEX, OPEX)
- Fragile
  - Complex interdependencies make it hard to diagnose and fix problems
  - More prone to human error (additional cost)
  - Upgrades, performance tuning, re-purposing all suffer
- Inflexible
  - Reluctance to change infrastructure once it is working
  - Does not support agile business (new software, business processes)
- Worsening
  - Technology innovations typically *exacerbate* the problem, preventing product innovations from being deployed

Solution: Self-managing systems

More Effects – Constituency Separation

- Different constituencies have different terms, grammars, and needs
  - Service Level Agreement meaning ***changes***
  - Business “speak” vs. networking commands
  - Different representations (e.g., use of UML)
- Relating network services and resources to business needs
  - Not reflected in EMS and NMS design
  - Lack of ***policy*** controlling allocation
  - Lack of ability to
    - Incorporate new knowledge
    - React in a timely manner to changes

There Is No Magic Button!

- Autonomics is NOT self-CHOP!
- Autonomics is about self-governance, based on internal and external knowledge
- But, this is technology…
- …Management also needs politics, economy, and arguably, chocolate

Autonomics Helps, Not Takes Over

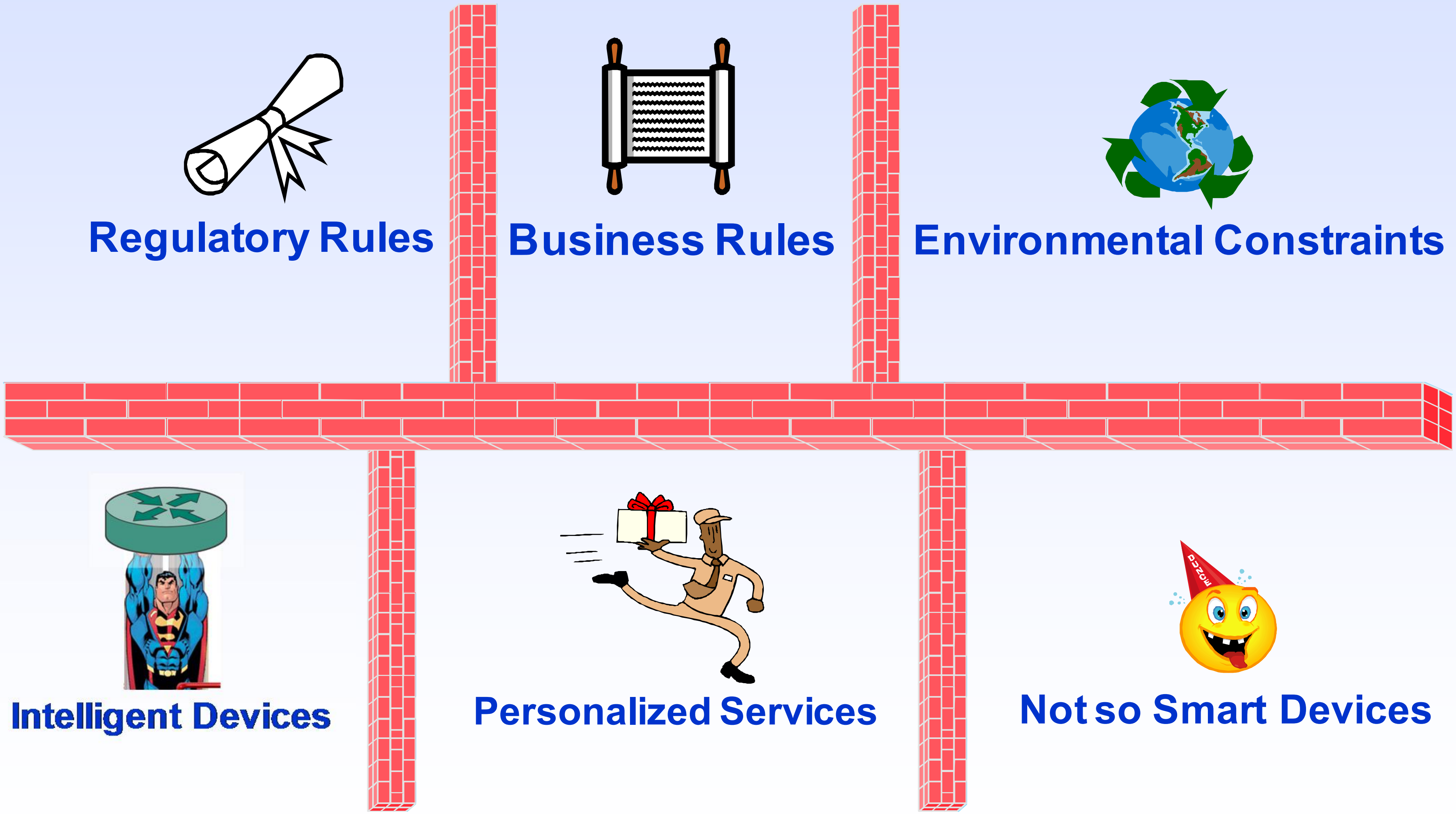
- People *express* what they want the system to achieve
- The system strives to manage its own behavior to optimally satisfy these multiple criteria, given resource and business constraints
  - Resources: Hardware, software, cost
  - Challenge is to develop the right technologies and architecture
- People and self-managing systems will *work together iteratively, in partnership with one another*
  - People will continue to do what they're best at doing
  - Systems will gradually assume more management burden
    - As they become more competent to do so
    - As people become more comfortable with this

Appendix: What Went Wrong?

Management is a Lot Harder than it Seems!

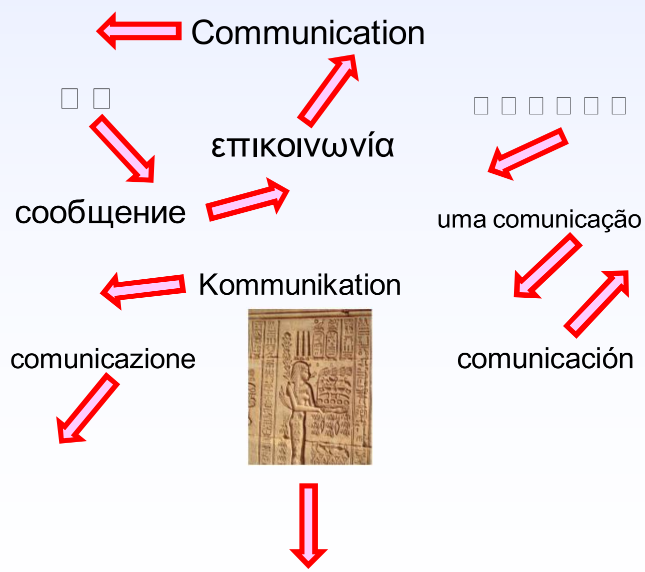
- Aggregates of elements may exhibit behavior not predictable from knowledge of individual behaviors
  - "The whole may be more screwed up than its parts"
- Causal determinacy still limited by simple statistical analysis and rudimentary correlation approaches
  - "If it fails this way, I know how to fix it (I think)"
- No ability of the system to "go beyond" precompiled knowledge and procedures
  - "We don't need no stinkin' AI"
- All current network management techniques require "human-in-the-loop" back-end analysis
  - Extensive system, deployment, and technology knowledge
  - Need for experts increases OPEX

A Stovepipe of Stovepipes



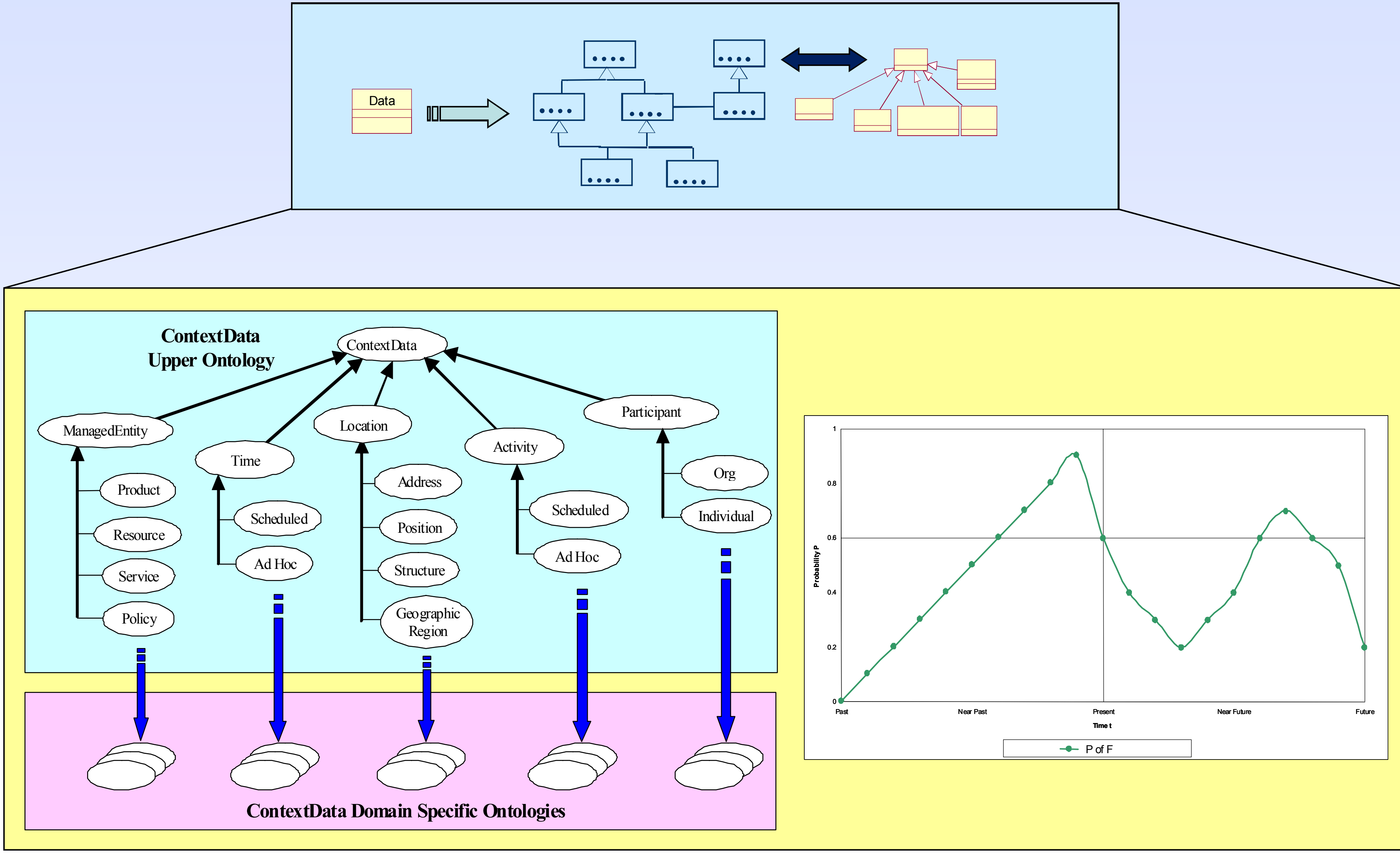
More Effects – Constituency Separation

- Different constituencies have different terms, grammars, and needs
  - The meaning of a Service Level Agreement ***changes*** between different constituencies



Appendix: Key Technologies – Knowledge Engineering

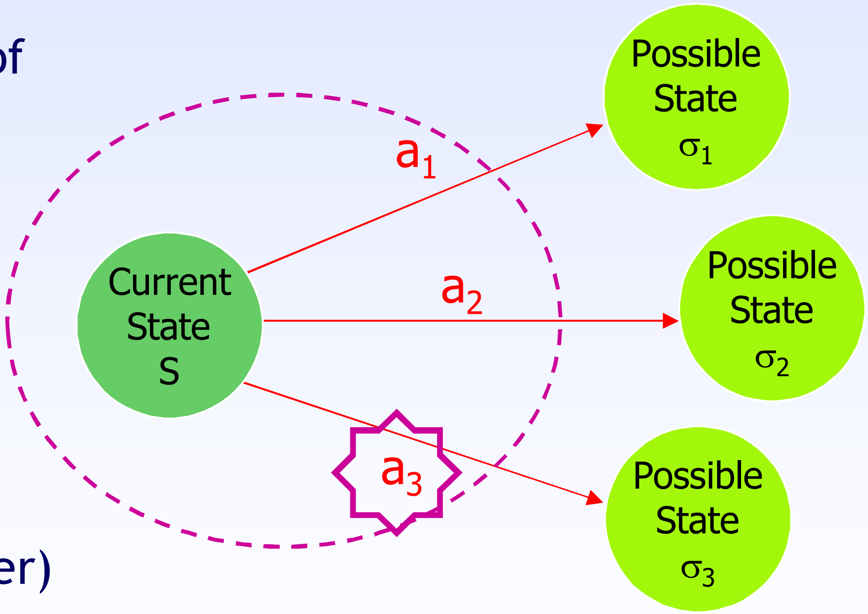
Modeling Situatedness



Some Types of Policy

- **Action Policy**
  - Specifies action *a* that should be taken in *current* state *S*

    IF(*Condition*) THEN (*Action*)
  - *Condition* specifies state or set of states
  - Objective:
    - Just apply policy
    - Resulting state not explicit
  - Knowledge:
    - Current state *S*
    - Action to take *a*
  - Policy author (human or computer) knows exactly what should be done

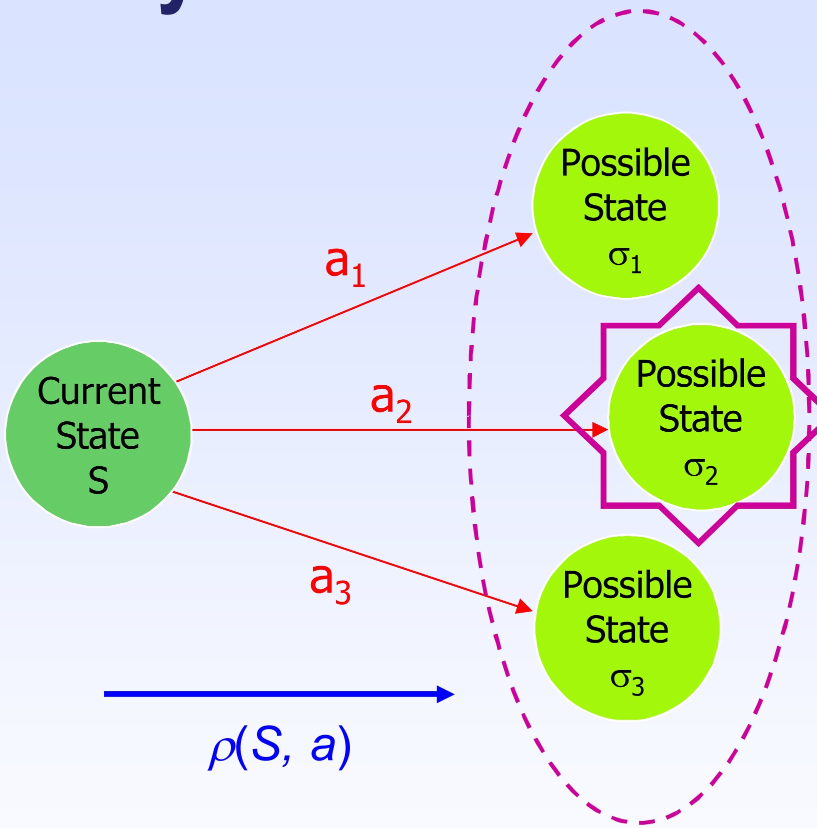


Rationality is *compiled into the policy*

Some Types of Policy

- Action Policy
- **Goal Policy**
  - Specifies desired *resulting* state ρ or criteria for set of states
    - Any member of desired states acceptable
  - System must compute action
    $a: S \rightarrow \rho$
  - Objective: Desired state ρ
  - Knowledge
    - Current state S
    - *System model*: $\rho(S, a)$

Rational behavior is *generated* by optimizer/planner



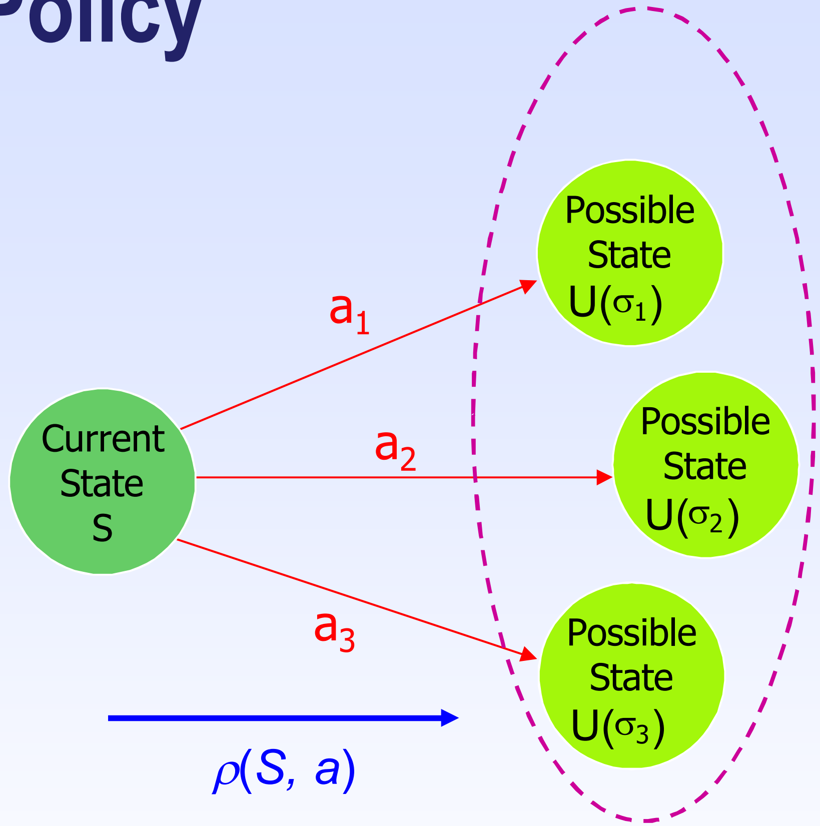
Compare to action policies:

- What we *want*, rather than what to do
  - Higher-level
  - More flexible
- Requires sophisticated models, optimization/planning algorithms

Some Types of Policy

- Action Policy
- Goal Policy
- **Utility Function Policy**
  - Function assigns a single real value to each *resulting* state
    $U(\rho) \rightarrow$ ⌚
  - Tradeoffs directly encoded, thus no conflicts
  - System must compute optimal action
  - Objective: Maximize $U(\rho)$
  - Knowledge
    - Current state *S*
    - *System model*: $\rho(S, a)$

Rational behavior is *generated* by optimizer/planner

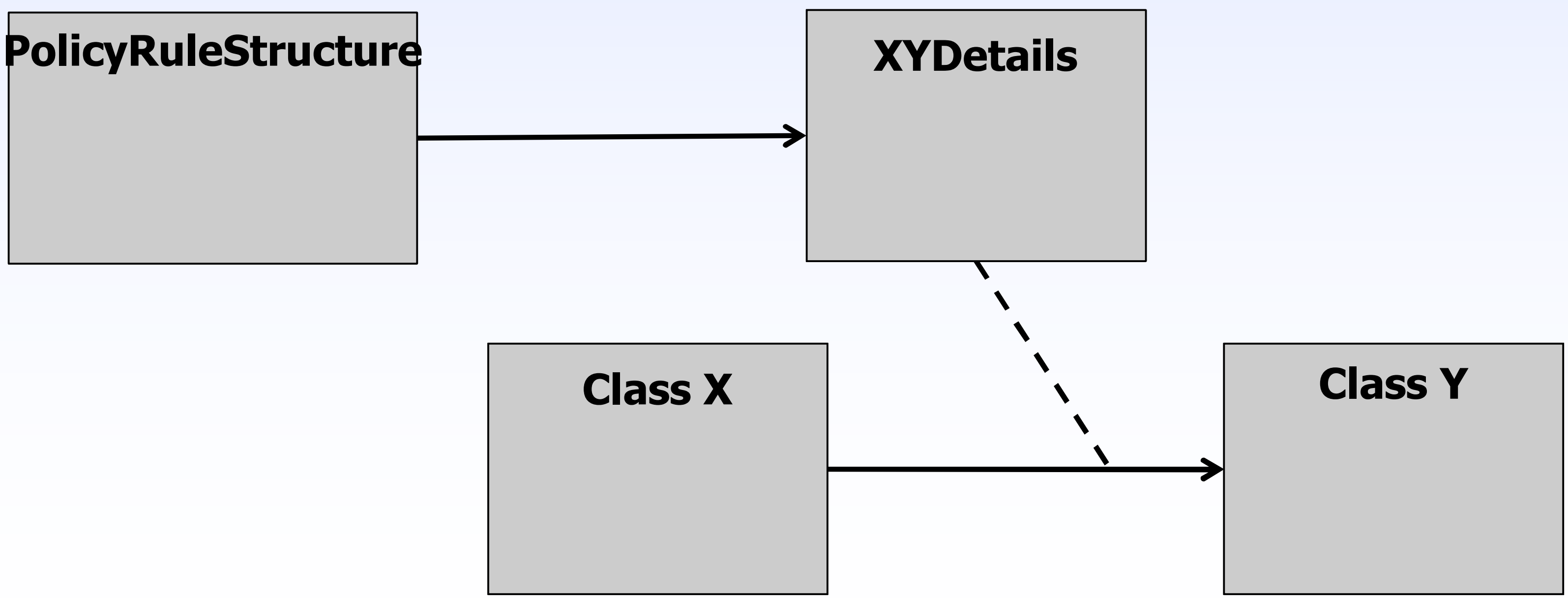


Compare to other policy types:

- High-level & flexible (like Goal)
- Range of state values (rather than binary Goal classification)
- Strict generalization of Goal
- No conflicts (like Action and Goal)
- Utility elicitation can be hard!

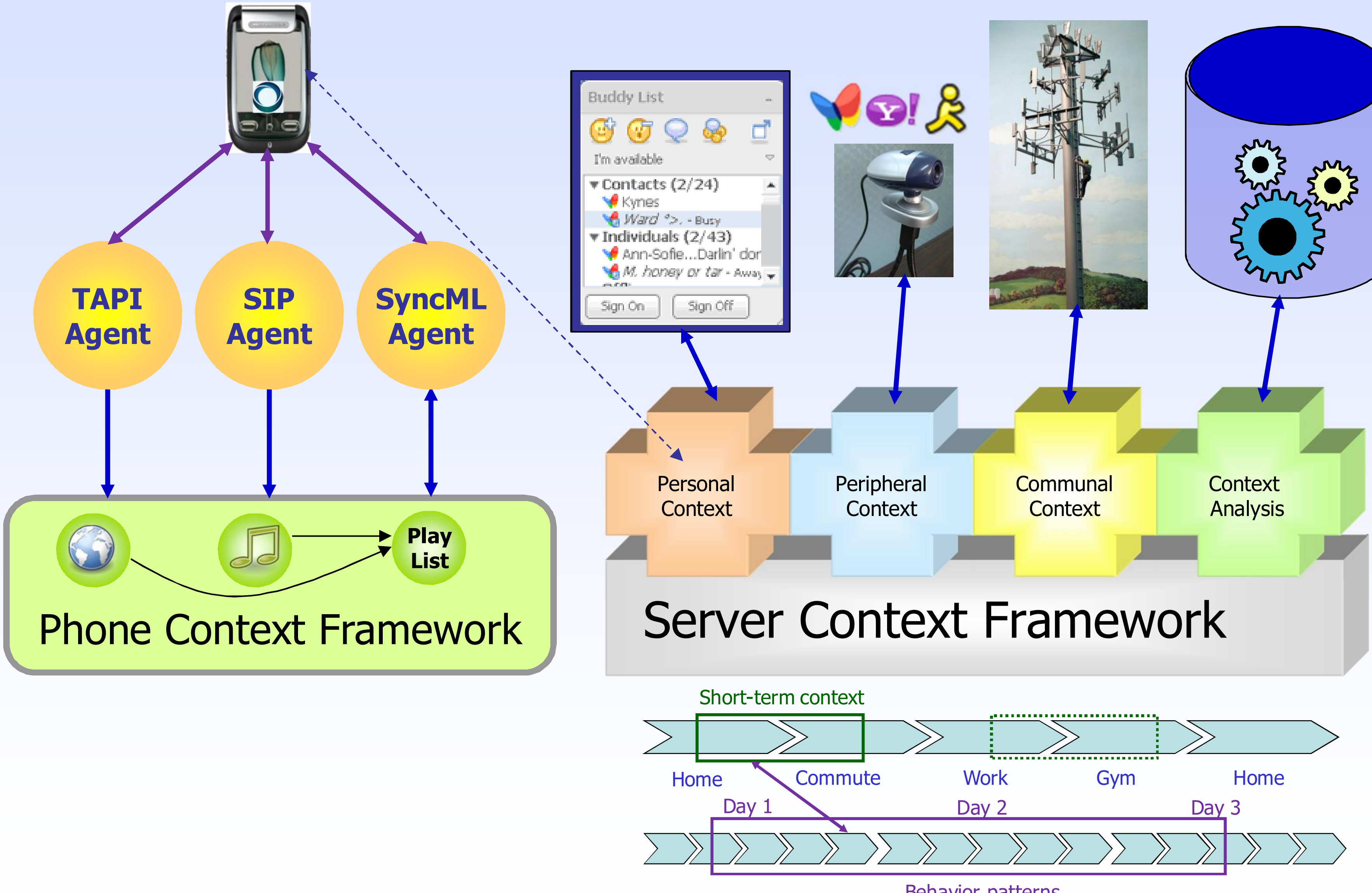
Policy Pattern

- Provide for policy-based management at *design time*
- Avoid various anti-patterns and tendency to special-case use of a common concept (i.e., policy) for different uses



Appendix: Key Technologies – Knowledge Engineering

Integrating short- and long-term Contexts



Appendix:
Key Technologies – Knowledge Engineering

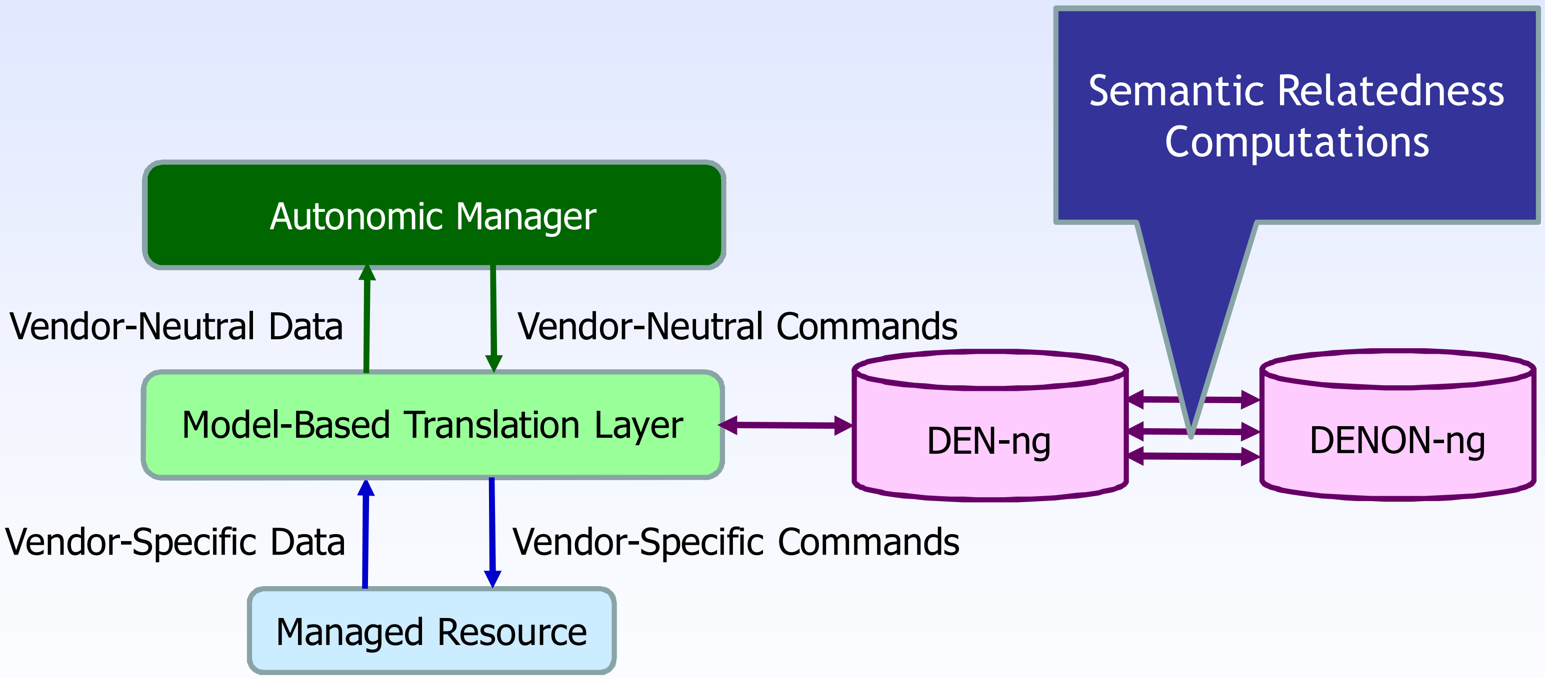
Definition

- *An ontology is a formal, explicit specification of a shared, machine-readable vocabulary and meanings*
  - *Contains entities and relationships to describe knowledge about the contents of one or more related subject domains throughout the life cycle of its existence*
  - *Formal means that the ontology is defined in a formal grammar*
  - *Explicit means that the entities and relationships used, and the constraints on their use, are precisely and unambiguously defined in a declarative language suitable for knowledge representation*
  - *Shared means that all users of an ontology will represent a concept using the same or equivalent set of entities and relationships*

Ontologies vs. Models

- Models are required because network management data
  - is in the form of models
  - is not specified using formal languages
- Ontologies are required because
  - they provide not just the terminology, but also the associated definitions, relationships and constraints of each term
  - they are specified using formal languages, which supports machine-based learning and reasoning
- Hence, we construct a formal specification of network data so that we can compute inferences and reason about what the data means
  - Construction done by integrating models and ontologies

Model-Based Translation



Semantic Relatedness with WordNet

- WordNet is a lexical network of English words
  - Nouns, verbs, adjectives, and adverbs are organized into networks of synonym sets (**synsets) that each** represent one underlying lexical concept and are interlinked with a variety of relations
  - A polysemous word will appear in one synset for each of its senses
- Supported relationships include hyponymy (is-a) and its inverse (hypernymy), synonymy, antonymy, and six meronymic relationships (component-of, member-of, instance-of, and their inverses)
- The relatedness of two words is equal to that of the most-related pair of concepts that they denote
  - rel(c1, c2) for semantic relatedness between two concepts c1 and c2, the relatedness rel(w1,w2) between two words w1and w2

$$\mathrm{rel}(w_1, w_2) = \max_{c_1 \in s(w_1), c_2 \in s(w_2)} [\mathrm{rel}(c_1, c_2)]$$

Semantic Relatedness Computation

- Tversky's semantic relatedness measure is:

$$\mathrm{sim}(A,B) = \frac{|S(A) \cap S(B)|}{|S(A) \cap S(B)| + \alpha(A,B)\,|S(A) \setminus S(B)| + (1-\alpha(A,B))\,|S(B) \setminus S(A)|}$$

  where "∩" means set intersection, " \ " means set difference, " ||" means set cardinality, and "α(A,B)" is a weighting factor (note that semantic relatedness is not necessarily symmetric (the simplest case being that the similarity of a subclass to its superclass is not the same as the similarity of the superclass to a subclass,)

- This formula defines the semantic relatedness of A and B in terms of
  - the semantics that are common to them
  - the semantics that are particular to A, and the semantics that are particular to B
- We modified the above to

$$sim(A,B) = \beta_{syn} \cdot sim_{syn}(A,B) + \beta_{hyp} \cdot sim_{hyp}(A,B) + \beta_{mer} \cdot sim_{mer}(A,B)$$

- where sim_{syn} , sim_{hyp} , and sim_{mer} denote the similarity between the synonyms, hypernyms, and meronyms of A and B, and the parameters β_{syn}, β_{hyp}, and β_{mer} denote a weighted value for these three similarity measures, respectively; each weight is greater than or equal to zero, and the sum of the three weights must equal 1

Different Types of Data

- There is a profound difference between modelling facts and modelling inferences
  - Facts that are observed or measured often do not need additional reasoning performed on them
  - Inferences can only exist by having reasoning performed to create them
- Network management data does not contain inferences, though inferences can be made
- We use *graphs* to combine knowledge extracted from models and ontologies
  - We define *semantic edges* as special constructs to associate knowledge from model elements with knowledge from ontologies (and vice-versa)

Appendix:
Exemplar Research

Key Management Goals

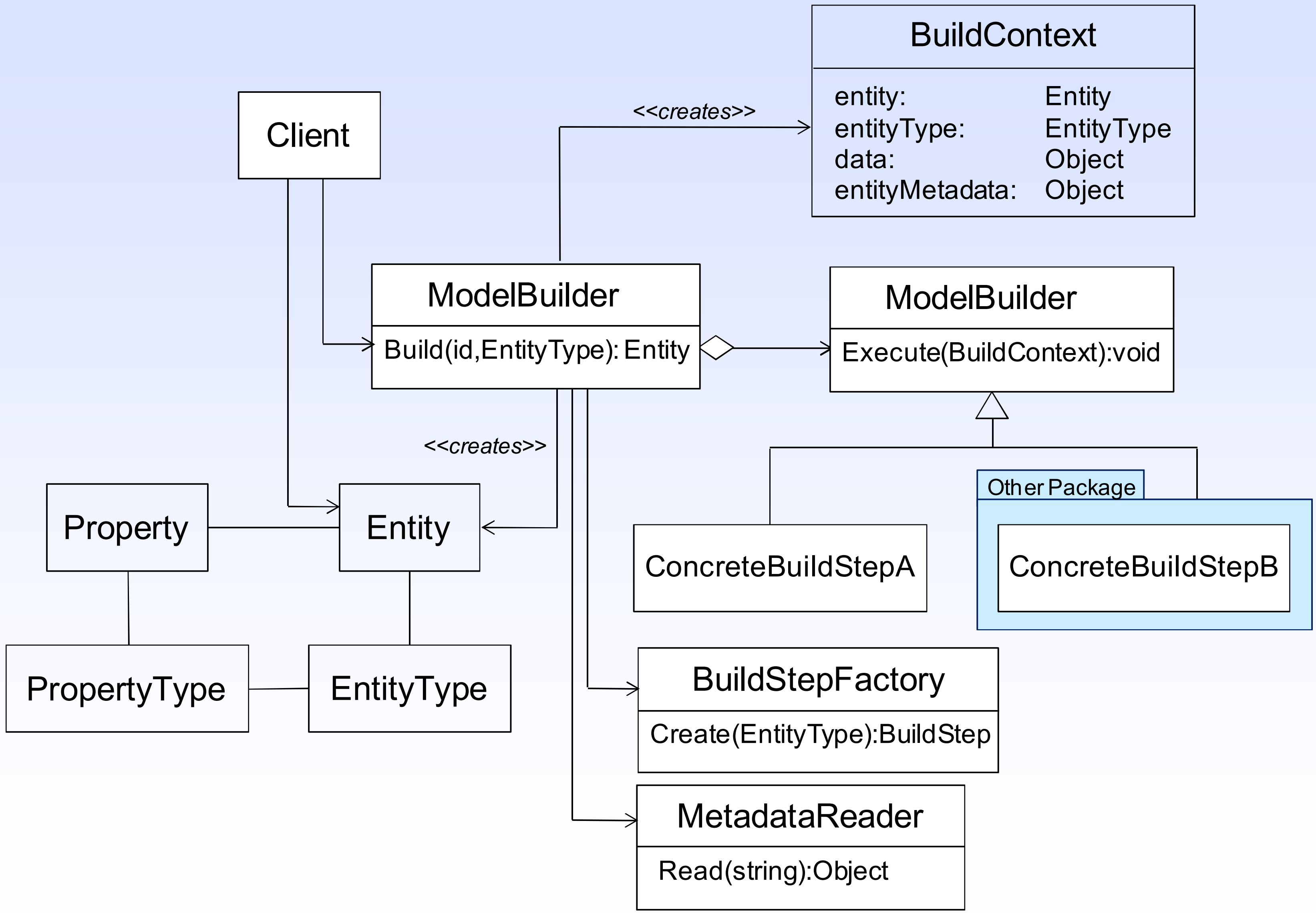
- Complexity, cost reductions, and pressure to manage the network as part of a service
  - Provide IT automation to reduce errors and OPEX
  - Use policy-based management to respond to changing business needs using SIEM and analytics
  - Use APM to ensure that application performance does not impact business processes and services
- Embrace business service management
  - Lifecycle management of IT resources and services to increase efficiency, flexibility, and provide compliance
- Embrace interoperability
  - Open source will drive interoperability and open formats

Appendix: Metadata-driven Behavior

Ensuring Consistent Behavior

- As the object model is revised, new entity types and subtypes may be added or changed
  - These *may* require changes in the behavior of objects
  - Instead of modifying the the object model entities (which requires code generation and redeployment)…
  - …use metadata and scripting
- Controlling Behavior via Scripting (e.g., JavaScript, Python, …)
  - Behavior is stored as data (not compiled) and hence can be changed without system redeployment
  - Dynamically executed (with no compilation) so it can be used as an interim solution
  - Requires the object model to have predefined hook points that allow the users to override system behavior by writing scripts
- Avoiding modifying scripts
  - Decouple scripts from the model by specifying script hook-points in the model

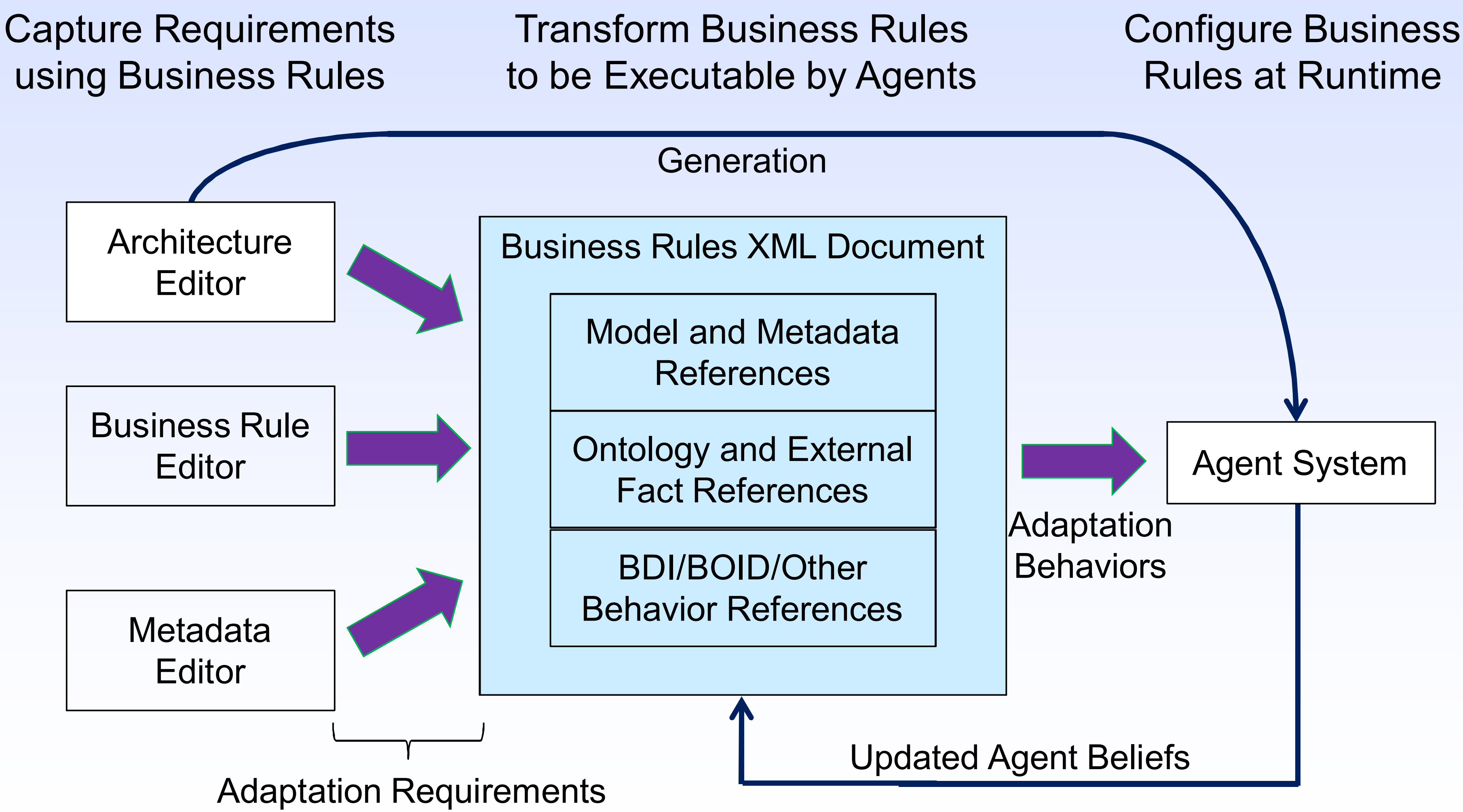
Simplified Implementation



Implementation Thoughts

- Use the DEN-ng model
  - Defines metadata, context, policy, and agents
  - Enables adaptive inter-agent behavior to be modeled using XML-based rule definitions
  - Transform requirement to rules that are dynamically interpreted
- Can use a variety of implementation options
  - Use JADE platform; ensure FIPA compliance for interoperability
  - Define agent actions as workflow processes
  - Define agent behaviors as state automata
  - Use SBVR and/or ontologies to define business rules
  - Use RIF or RuleML to define rules (for interoperability)
  - Use rule engines, such as DROOLS or ILOG, to execute actions

Simplified System Diagram



Appendix:
Some of My Sample Papers

Journal Publications (1)

- J.M. Kang, J. Strassner, S. Seo, J.W.K. Hong, "*Autonomic Personalized Handover Decisions for Mobile Services in Heterogeneous Wireless Networks*", Journal of Computer Networks, vol 55, issue 7, pages 1520-1532, May 2011
- J. Strassner, J.N. de Souza, D. Raymer, S. Samudrala, S. Davy, K. Barrett, "*The Design of a Novel Context-Aware Policy Model to Support Machine-Based Learning and Reasoning*", Journal of Cluster Computing, Volume 12, Issue 1, pages 17-43, March, 2009
- J. Strassner, J.N. de Souza, S. van der Meer, S. Davy, K. Barrett, D. Raymer, S. Samudrala, "*The Design of a New Policy Model to Support Ontology-Driven Reasoning for Autonomic Networking*", Journal of Network and Systems Management, Volume 17, Issue 1, pages 5-32, March 2009
- J. Strassner, S. van der Meer, D. O'Sullivan, S. Dobson, "*The Use of Context-Aware Policies and Ontologies to Facilitate Business-Aware Network Management*", Journal of Network and System Management, Volume 17, Number 3, pages 255-284, September , 2009
- S. Balasubramaniam, D. Botvich, B. Jennings, S. Davy, W. Donnelly, J. Strassner, "*Policy-Constrained Bio-Inspired Processes for Autonomic Route Management*", Journal of Computer Networks, pages 1666-1682, 2009
- S. Davy, B. Jennings, J. Strassner, "*The Policy Continuum – Policy Authoring and Conflict Analysis*", Computer Communications Journal, Elsevier, Volume 31, Issue 13, pages 2981-2995, August 2008

Journal Publications (2)

- X. Gu, J. Strassner, J. Xie, L. Wolf, T. Suda, "*Autonomic Communications: Where Are We Now?*", Proc. of the IEEE, Vol. 96, No 1, pages 143-154, January, 2008
- J. Strassner, N. Agoulmine, E. Lehtihet, "*FOCALE – A Novel Autonomic Networking Architecture*", International Transactions on Systems, Science, and Applications (ITSSA) Journal, Vol. 3, No 1, pp 64-79, May, 2007
- J. Strassner, D. O'Sullivan, D. Lewis, "*Ontologies in the Engineering of Management and Autonomic Systems: A Reality Check*", Journal of Network and Systems Management, Vol 15, No 1, pages 5-11, March, 2007
- B. Jennings, S. van der Meer, S. Balasubramaniam, D. Botvich, M. Ó Foghlú, W. Donnelly, J. Strassner, "*Towards Autonomic Management of Communications Networks*", IEEE Communications Magazine, Vol. 45, no. 10, pages 112-121, October, 2007
- A. Wong, P. Ray, N. Parameswaran, J. Strassner, "*Ontology mapping for the interoperability problem in network management*", IEEE Journal on Selected Areas in Communications, Vol. 23, Issue 10, pages 2058-2068, October 2005

Panel Slides

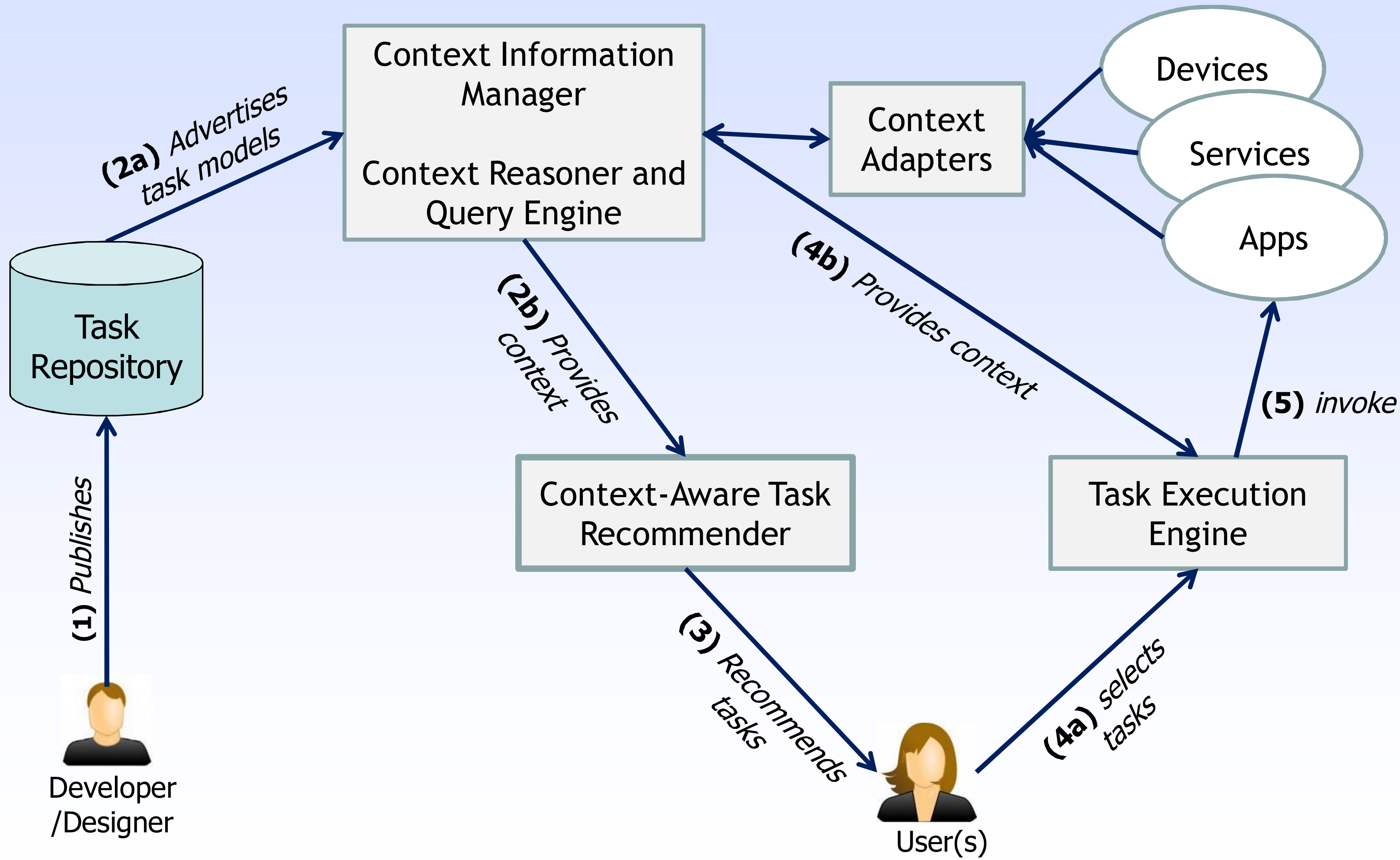
Smart Space Definition

- What is a smart space?
  - "Seamlessly integrating computational elements into the fabric of everyday life…" [Weiser **1991**]
  - Smart objects link the digital and physical worlds (note: my definition adds "through semantics")
  - Realized by enabling objects to be aware of their users and environment to proactively provide resources and services *with little or no human intervention*
- What are its characteristics
  - Provide information and analysis and/or
  - Provide automation and control
  - **Change today's business model**, since it restructures business around dynamic, not *static,* information

Problems to Overcome

- *Complexity of use*
  - Variety of devices, UIs, etc, require rich features that often exceeds the capacity of hosting devices
  - Users need to understand how to map devices' functions to their tasks & sub-tasks
- *Invisibility vs. Feature Overload*
  - IFF technologies can vanish into our environment, how do users recognize the extra features that smart objects can provide?
- *Inconsistent Operation*
  - Users may be frustrated by the lack of constant services due to the high frequency of adding/removing devices and services from the environment
  - Different objects may provide different services or worse, conflict with each other, *especially if current applications (which are not goal-based) are robotically translated into smart objects*

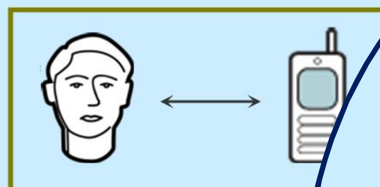
Simplified Overview



Smart Object Interaction Evolution

Goal-Oriented

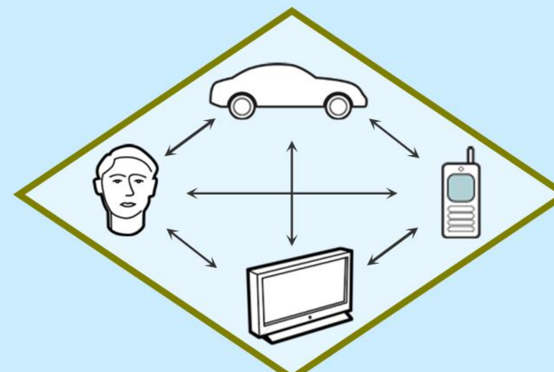
Personalized,
Intuitive UI



TOMORROW

Ubiquitous

Predictive,
Pervasive UI



THE FUTURE

Computing Using Smart Objects