Vision of the Future Internet

Dimitri Papadimitriou
Alcatel-Lucent Bell Labs

PARADISO Workshop
Brussels, Belgium
November 23, 2010

Fundamental Questions

- Q1: could the Internet architecture itself become the limiting factor of its growth and deployment of new applications and by when ?
- Q2: Internet architecture incrementally and reactively extended but up to which limit?

  vs what's the impact of Internet architecture limits but up to which extend?

- Hints
  - It is complex to measure how the Internet currently perform (hence even more complex to extrapolate how new architectural principles and components would perform)
  - Better performance or functionality define necessary but not sufficient condition for change (need also to demonstrate limits of current design)

Current Design Objective

- Optimize ratio $\frac{\text{cost x complexity}}{\text{performance}}$
  - Executability by limiting|fixing system complexity (time and resource)
  - Functionality is pre-determined at system design time (not at running time)
- Condition
  - Commonly shared functional objectives
  - Functional objectives limited in number, generic, and homogeneous
- Will these conditions be met in the future ?

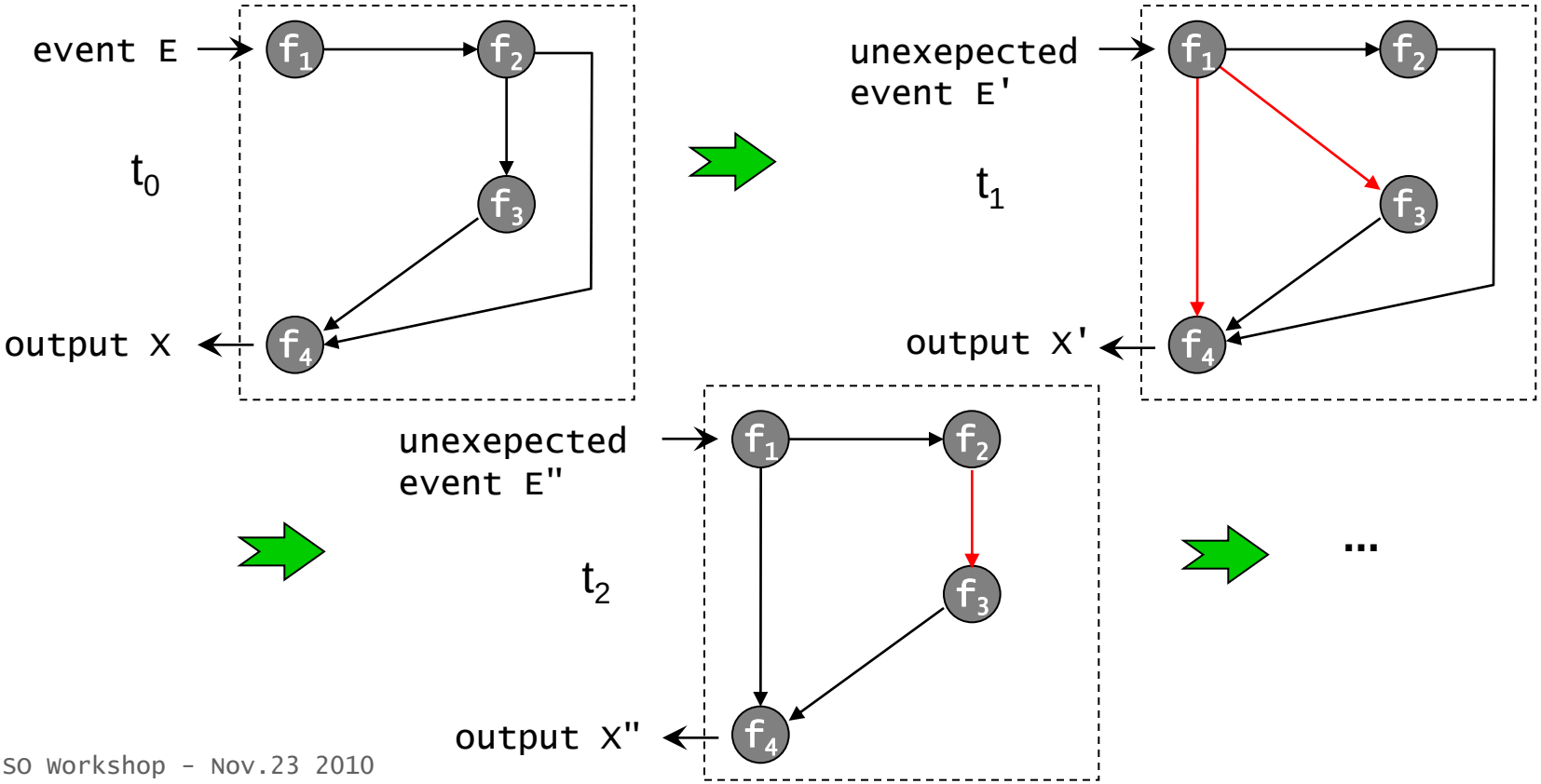
Some elements of answer

- Response: hard to infirm or confirm
  - Beyond certain proven limits, understanding how the current system actually performs is a complex task (thus even more complex to determine how it will perform)
- Therefore, need to design for
  - Flexibility of the system over time
  - Evolutivity of the system over time
  - Autonomy and adaptivity in interpretation, decision and execution (closed feedback loop)
- Distribution and dynamicity (e.g. traffic, topology, etc.) is part of the problem space
  - Note certain environment are cooperative others non-cooperative

Design for Flexibility

- **Flexibility**: capacity of a system to adapt/react in a timely and cost-effective manner when internal or external events occur that affect its value delivery

-> ability of a system to **response to uncertainty** in a manner to sustain or increase its value delivery over time (uncertainty level determines flexibility value)



Design for Flexibility

- **Design implications**
  - **Design principle: response to uncertainty**
    - Unexpected / unattended events
    - Variability of expected events
    - Heterogeneity of running conditions and events

    Note: Planning under uncertainty (Dantzig 1999 *) vs tradeoff between tractability and optimality

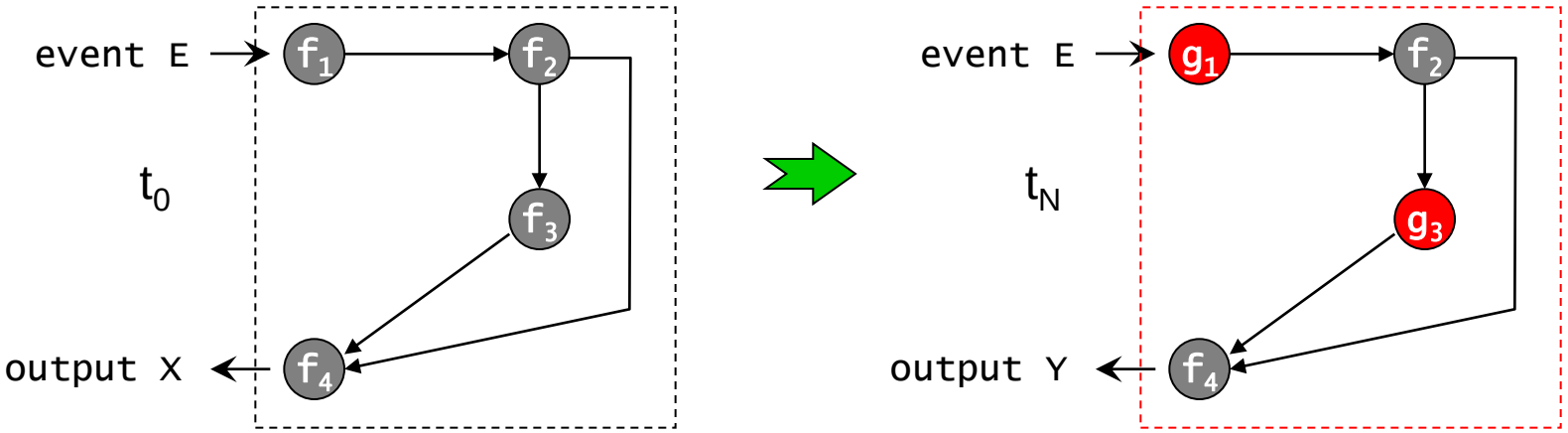
  - **Self-organization**: from fixed relationship between components (at design time) to dynamic relationship (at running time)
    - Trade-off between survivability of individual components and their cooperation

  - Promising iff "base" functions (time invariants) are permanently available

(*) Seminal paper ""“Linear programming under uncertainty”, Management Science, 1955

Design for Evolutivity

- Evolution: change of properties/capabilities of a system over time towards a certain direction



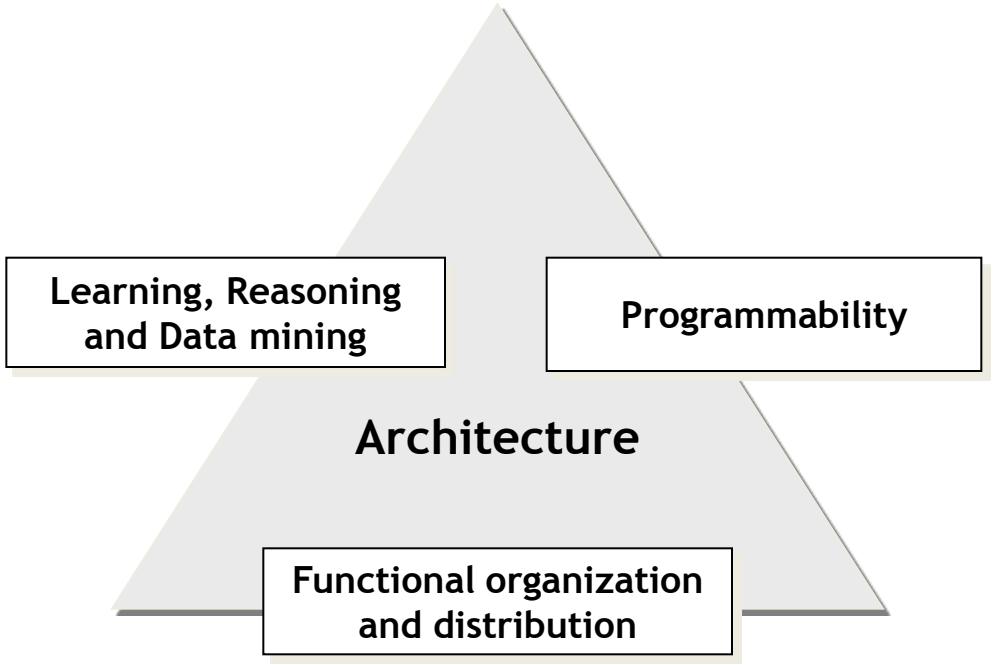
- Design implications
  - Design principle: self-evolutive components/process
  - Determine architectural time invariants (static) vs evolutive components (dynamic)
    - not all components will evolve at the same speed

Couple of observations

- Performance optimization (valuable under certainty) vs flexibility (valuable under uncertainty)
  - Performance decreases resiliency, and robustness (hence longevity) under uncertainty
- Current practice of design / dimensioning by "over-provisioning" is a primary form of robustness/resiliency against uncertainty
  - Probably one reason of the longevity of the current architecture
- **Self => Learning** central paradigm to enable flexibility, evolutivity, etc.
  - However distributed and dynamic nature of networks makes their applicability a challenge on its own

Conclusion

Evolutivity (evolvable architectural components vs time invariant components)



Flexibility (modularity, composability, dynamic relationship, etc.) and cooperation

Meet design objectives and properties (**scalability**, **security**, **accountability**, reliability, robustness, etc)