# Modeling the Internet as a Complex System

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## The goal of the modeling exercise:

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- Understanding past and future evolution of the Internet infrastructure.

## Models of complex systems that aren't sufficient for this particular goal:

- Game theory.
- Physics-style models of many small things all the same.
- Doyle-style control theory and dynamical systems.
- ...

## Components of such a model:

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- The layered IP architecture.
- Changes over time (e.g., the general overprovisioning of backbones and transoceanic links over the last five years).
- A decentralized system, with players including companies, entire industries, ISPs, etc, rather than just individuals.
- The role (or absence of a role) of IETF standards, and of other standards.
- Economic and political factors.
- The intrusion of the real-world (e.g., firewalls, etc.).
- Chicken-and-egg deployment issues.

## Specific topics:

- IPv6.
- QoS.
- Multicast.
- Middleboxes.
- ECN.
- Instant messaging.
- Security.
- DNS.
- Routing.
- Possible paths for future evolution.

## Conceptual Models for The Evolution of QoS

| Modeling Aspect: | Details: |
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| The Time Line. | * Heavy congestion in the early to mid 90's.<br><br>* Overprovisioning in backbones in the late 90's and on.<br><br>* Overprovisioning, now, in international links.<br><br>* Recent overprovisioning at peering points.<br><br>* The continued use of end-to-end congestion control for best-effort traffic.<br><br>* The beginning deployment of VoIP. |

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| Protocols,<br><br>Standards,<br>and Architectural<br><br>Factors. | * Congestion control mechanisms for streaming media.<br><br>* Integrated Services: A disregard for administrative boundaries within networks.<br><br>* Differentiated Services: Standardized in terms of per-hop behaviors, but not in terms of end-to-end performance.<br><br>* The use of IPSEC, NATs, and other IP tunnels introduces difficulties for QoS deployment.<br><br>* Intserv reservations within diffserv flows?<br><br>* Interactions of QoS with the dynamic nature of routing. |

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| Economic and Political Factors: | * The decomposition of the Internet into different administrative domains.<br><br>* Difficulties in billing for per-flow services. |
| Implementation Issues: | * What gets deployed first, host applications or network infrastructure?<br><br>* The costs and slow time-scale of introducting additional functionality in routers.<br><br>* QoS for unicast only, or for multicast?<br><br>* Receiver-based or sender-based design? |