Center for LifeLong Learning & Design
University of Colorado at Boulder

Wisdom is not the product of schooling
but the lifelong attempt to acquire it.
- Albert Einstein

Seeding, Evolutionary Growth, and Reseeding

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and
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Complex Systems: Why Do They Need to Evolve and How Can Evolution Be Supported

- **the basic message:** computational systems of the future
  - will be complex, embedded systems
  - need to be open and not closed
  - will evolve through their use

- **examples:**
  - domain-oriented design environments (DODEs)
    * kitchen design: extensions for microwaves, critics checking appliances against the wall (unless island kitchens), designs for disabled people (blind, in wheelchairs)
    * computer network design: new computers, new communication devices
  - Envisionment and Discovery Collaboratory (EDC) (versus SimCity)
  - operating systems (Linux) and high-functionality applications (MS-Word, Canvas, ...)
  - courses as seeds
  - buildings (see Stewart Brand: “How Buildings Learn - What Happens after they’re built”)

The Past and The Future

Theme	Past	Future
focus of interest	algorithm	complex system
relevant theories	physics, mathematics	biology
design methodology	building from scratch	reuse, redesign, adaptation, evolution

- **claims/challenges:**
  - (many) software systems must evolve (they cannot be completely designed prior to use)
  - (many) software systems must evolve at the hands of the users
  - (many) software systems must be designed for evolution

Problems of Complex (Computer) System Design

- problems in semantically rich domains ----> thin spread of application knowledge
- modeling a changing world ----> changing and conflicting requirements
- turning a vague idea about an ill-defined problem into a specification ----> “design disasters”, “up-stream activities”
- symmetry of ignorance ----> communication and coordination problems

Answers to Problems of System Design

- problems in semantically rich domains → thin spread of application knowledge — **domain-orientation**

- modeling a (changing) world → changing and conflicting requirements — **evolution**

- turning a vague idea about an ill-defined problem into a specification → "design disasters", "up-stream activities" — **integration of problem framing and problem solving**

- symmetry of ignorance → communication and coordination problems — **representation for mutual understanding and mutual learning**

Theory and Practice of Design—A Quest for Evolution

Dawkins — "The Blind Watchmaker": big-step reductionism cannot work as an explanation of mechanism; we can't explain a complex thing as originating in a single step

Simon — "The Sciences of the Artificial": complex systems evolve faster if they can build on stable subsystems

Petroski — "To Engineer Is Human": the role of failure in successful design

Brooks — "No Silver Bullet": successful software gets changed, because it offers the possibility to evolve

Polanyi — "The Tacit Dimension": knowledge is tacit → we know more than we can say

Karl Popper: Conjectures and Refutations

- John Archibald Wheeler: “Our whole problem is to make the mistakes as fast as possible.” (foreword to the book) **— breakdowns as opportunities**

- criticism of our conjectures is of decisive importance and all of our knowledge grows only through the correcting of our mistake **— critiquing systems**

- there are all kinds of sources of our knowledge but none has authority — **symmetry of ignorance and mutual competency**

- the advance of knowledge consists in the modification of earlier knowledge — **evolution**

The Economic Forces for Evolution in Software Systems

- **the most critical software problem is the cost of maintenance and evolution**
    - empirical studies of software costs: two-thirds of the costs of a large system occur after the system is delivered
    - claim: much of this cost is due to the fact that a considerable amount of essential information (such as design rationale) is lost during development and must be reconstructed by the designers who maintain and evolve the system

- **make enhancements and evolution “first class” activities in the lifetime of an artifact**
    - accept the reality of change
    - acknowledge increased up-front costs (cognitive and economic)

Integrating Problem Framing and Problem Solving

- **Simon:**
  "in oil painting every new spot of pigment laid on the canvas creates some kind of pattern that provides a continuing source of new ideas to the painter. The painting process is a process of cyclical interaction between the painter and canvas in which current goals lead to new applications of paint, while the gradually changing pattern suggests new goals."

- **Rittel:**
  one cannot understand a problem without having a concept of the solution in mind
  one cannot gather information meaningfully unless one has understood the problem but one cannot understand the problem without information about it

- **concepts derived from these quotes:**
  - back-talk of artifacts/situations
  - reflection-in-action
  - incremental development
  - co-evolution between problem and solution
  - integration / co-evolution of upstream and downstream activities

- **empirical study: McGuckin**

AEGIS: Human Nature versus Human Error

- core of Aegis (worth 600 millions dollars): combat information center (CIC)

- in the Strait of Hormuz incident
  - search in a ordinary paperback airline flight guide
  - scenario fulfillment

- congressional hearings (Navy, Psychologists, ...)
  - Navy: *“Aegis system's performance was excellent — it functioned as designed”*
  - Psychologist: *“Aegis software was churning out more unrelated data than the crew could readily digest”*

- Aegis was the wrong system in the wrong place: designed for the open ocean, not for the twenty-five mile Strait of Hormuz → unarticulated background knowledge

- limits in testing (we test for what we are anticipating)

Three Generations of Design Methods from the History of Architectural Design

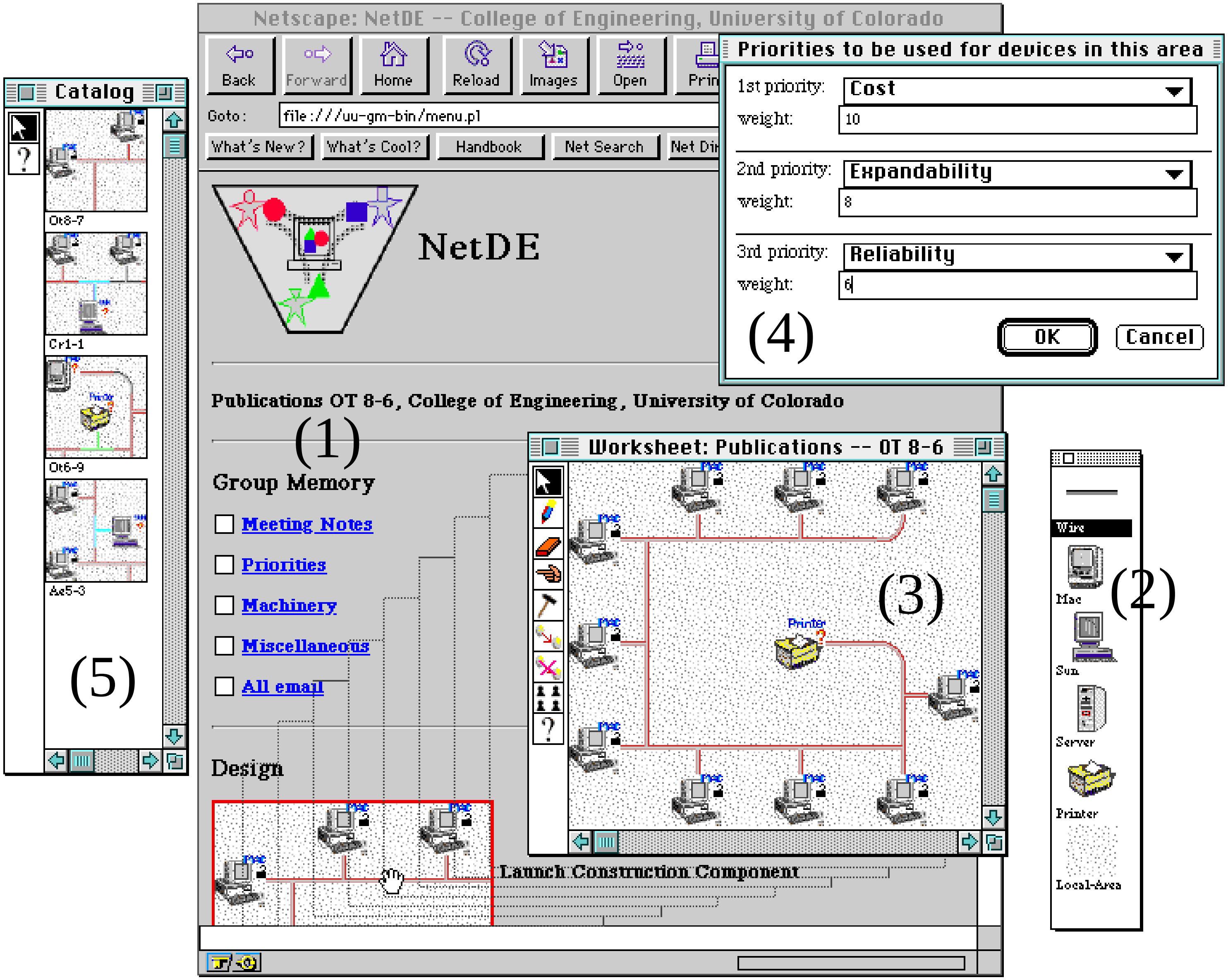
- **1st Generation (before 1970):**
  - directionality and causality
  - separation of analysis from synthesis
  - major drawbacks: (a) perceived by the designers as being unnatural, and (b) does not correspond to actual design practice

- **2nd Generation in the early 70'es:**
  - participation — expertise in design is distributed among all participants
  - argumentation — various positions on each issue
  - major drawback: insisting on total participation neglects expertise possessed by well-informed and skilled designers

- **3rd Generation (in the late 70'es):**
  - inspired by Popper: the role of the designer is to make expert design conjectures
  - these conjectures must be open to refutation and rejection by the people for whom they are made (---> end-user modifiability)

Domain-Oriented Design Environments and Evolution

- support the construction and evolution of domains (program families)
- empirical fact: reuse is most successful within domains
- not just objects, but:
  - case libraries (different granularity)
  - critiquing (accumulated “wisdom” of a community of practice, “virtual” stakeholders)
  - specification component — partial characterization of a situation model
  - simulation — to understand the behavior
  - argumentation — to explore the rationale behind the artifact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Priorities
Machinery
Miscellaneous
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Priorities to be used for devices in this area
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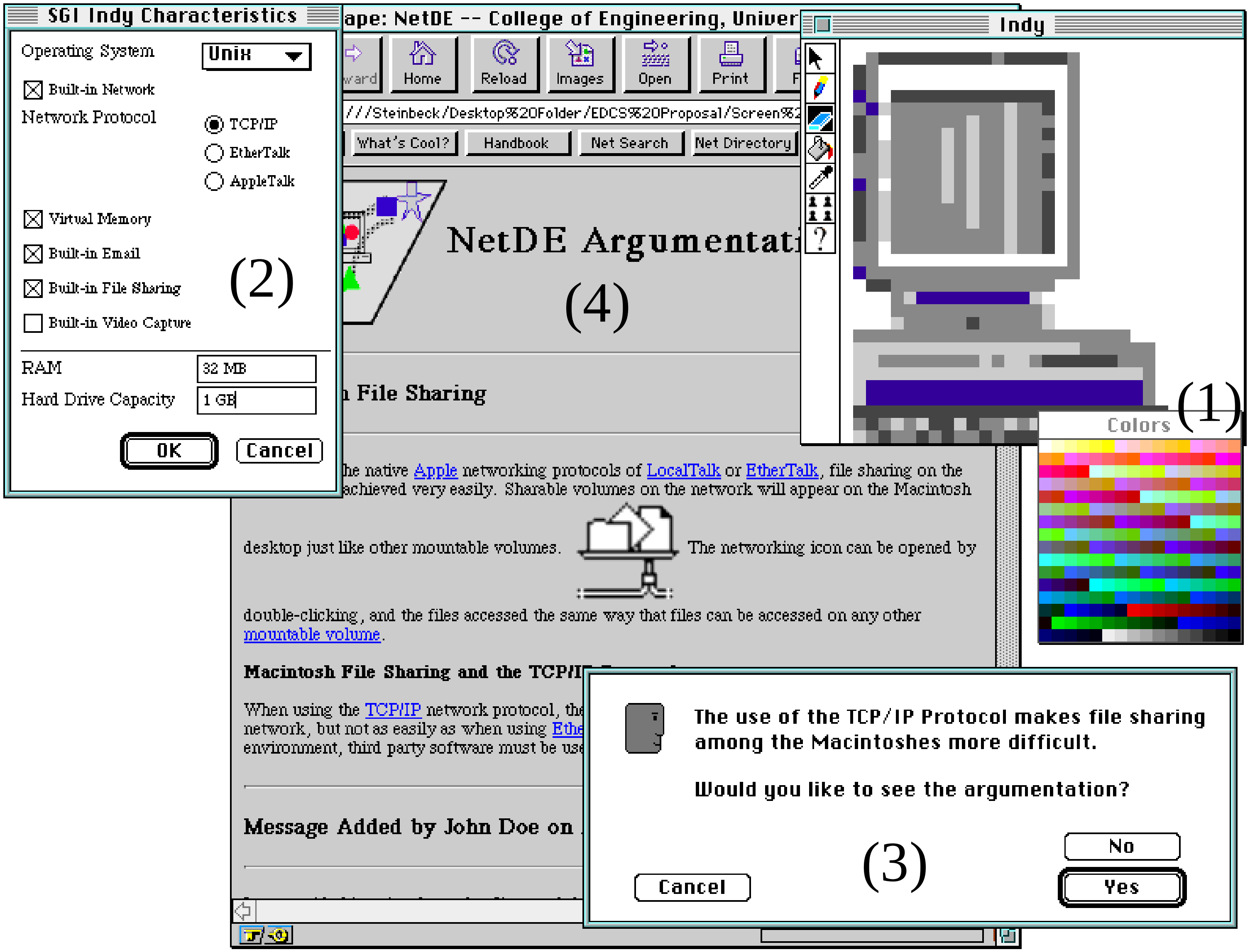
SGI Indy Characteristics
Operating System
Unix
Built-in Network
Network Protocol
TCP/IP
EtherTalk
AppleTalk
Virtual Memory
Built-in Email
Built-in File Sharing
Built-in Video Capture
RAM
32 MB
Hard Drive Capacity
1 GB
OK
Cancel
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ward
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Print
///Steinbeck/Desktop%20Folder/EDCS%20Proposal/Screen%2
What's Cool?
Handbook
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n File Sharing
he native Apple networking protocols of LocalTalk or EtherTalk, file sharing on the
achieved very easily. Sharable volumes on the network will appear on the Macintosh
desktop just like other mountable volumes.
The networking icon can be opened by
double-clicking, and the files accessed the same way that files can be accessed on any other mountable volume.
Macintosh File Sharing and the TCP/IP
When using the TCP/IP network protocol, the
network, but not as easily as when using Ethe
environment, third party software must be use
Message Added by John Doe on
Indy
(1)
Colors
The use of the TCP/IP Protocol makes file sharing among the Macintoshes more difficult.
Would you like to see the argumentation?
No
Yes
Cancel
(3)

Examples of DODEs

- user interface design — **Framer**
- floor plan design for kitchens — **Janus, KID**
- graphics software — **Explainer**
- computer network design — **Network, Pronet**
- water management — **Cadswes** (with CU research center)
- Cobol programming and service provisioning — **GRACE** (with NYNEX)
- voice dialog design — **VDDE** (with USWest)
- lunar habitat design — **HERMES** (with NASA)
- graphic arts, information design, information visualization — **Schemechart, Chart ‘n’ Art**
- multi-media design environment — **eMMa** (with SRA)

Seeding, Evolutionary Growth, and Reseeding

- **seeding**
  - seed a domain-specific DODE using the domain-independent, multi-faceted architecture
  - provide representations for mutual learning and understanding between the involved stakeholders
  - make the seed useful and usable enough that it is used by domain workers

- **evolutionary growth**
  - co-evolution between individual artifacts and the DODE
  - learning on demand and end-user modifiability complement each other
  - emerging human resources: local developers, power users, gardeners

- **reseeding**
  - formalize, generalize, structure
  - a social and technical challenge

- **success example of the SER model:**
  - development of operating systems
  - open source movement
  - courses as seeds

Evolution at All Three Levels

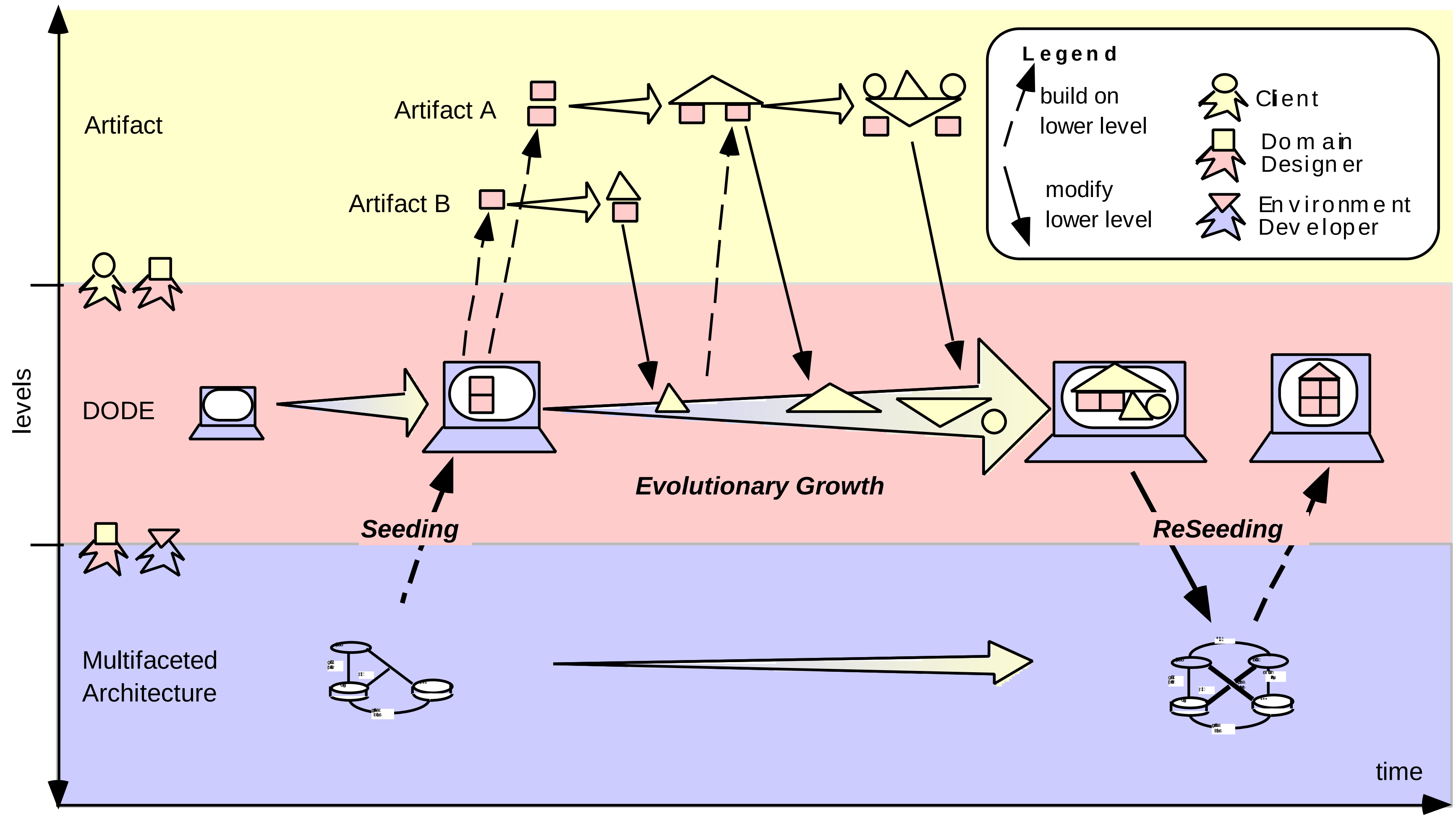
- evolution at the **conceptual framework** level
  - end-user modifiable DODEs
  - example: multifaceted, domain-independent architecture

- evolution of the **domain**
  - evolution was driven by new needs and expectations of users as well as new technology
  - example: computer network design

- evolution of **individual artifacts**
  - long-term, indirect collaboration
  - design rationale
  - example: the computer network at CU Boulder

- **co-evolution**
  - problem framing and problem solving (specification and implementation)
  - individual artifact and generic, domain-oriented design environment

The Seeding, Evolutionary Growth, and Reseeding (SER) Model



The Evolution towards End-User Modifiable DODEs

- General Programming Environments, e.g., Lisp, ...

  → **limited reuse**

- Object-Oriented Design, e.g., Smalltalk, Clos, C++, ...

  → **lack of domain-orientation**

- Domain-Oriented Construction Kits, e.g., Pinball, Music Construction Kits

  → **no feedback about quality of artifact**

- Constructive Design Environments, e.g., critics, explanations

  → **design is an argumentative process**

- Integrated Design Environments, e.g., combining construction and argumentation

  → **lack of shared context**

- Multifaceted Architecture

  → **limited evolution**

- **Programmable End-User Modifiable Design Environments**

Understanding Pitfalls Associated with Evolutionary Design

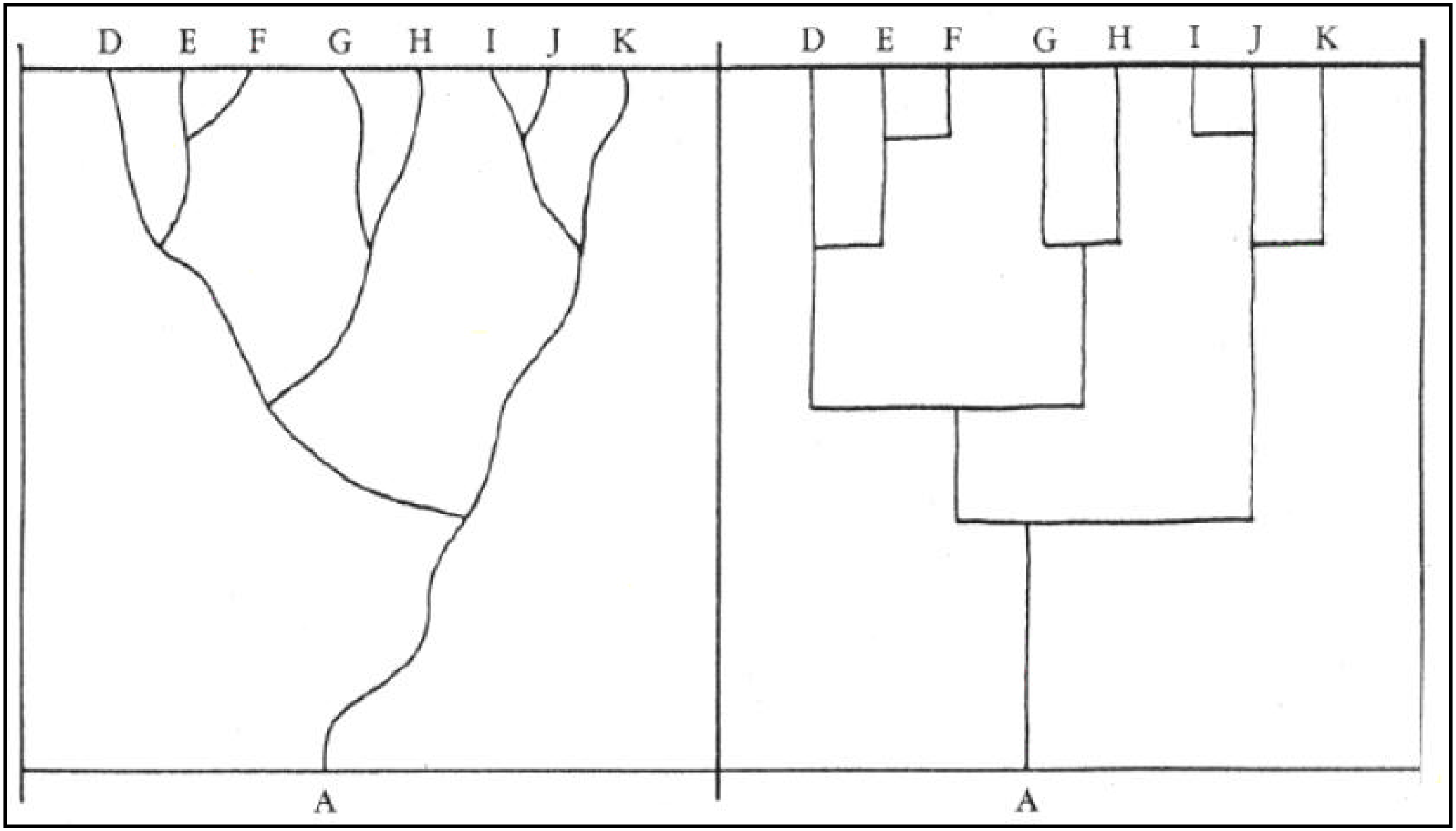
- **example:**
  - Oregon Experiment (Alexander et al., 1975)
  - a housing experiment at the University of Oregon instantiating the concept of end user-driven evolution
  - an interesting case study that end user-driven evolution is no guarantee for success
- **the analysis of its unsustainability indicated two major reasons:**
  - there was a lack of continuity over time
  - professional developers and users did not collaborate, so there was a lack of synergy
- **rationale for reseeding:**
  - making evolutionary development more predictable)
  - developers and users engage in intense collaborations → with design rationale captured, communication enhanced, and end user modifiability supported, developers have a rich source of information to evolve the system in the way users really need it

Evolution in Biology versus Evolution in the Human-Made World — a Word of Caution

- **the evolutionary metaphor must be approached with caution because**
  - there are *vast differences* between the world of the made and the world of the born
  - one is the result of purposeful human activity, the other the outcome of a random natural process.

- **does software develop according to the “punctuated equilibrium” theory?**
  - if yes, what causes the periods of increased change (subroutines, object-oriented programming, the world-wide web)?

Punctuated Equilibrium



Prototypes of Systems Supporting Evolution

- **Modifier** (end-user modifiability component of Janus)
  - mechanisms to add new objects and new behavior by the domain designer

- **Gimme**
  - web-based group memory system
  - supports communication between all stakeholders

- **Expectation Agents** (with NYNEX, UC Irvine)
  - support communication between developers and end-users
  - observe actions of end-users and compare them to descriptions of the intended use

- **Chart ‘n Art** (self-disclosure)
  - a gentle transition from direct manipulation interfaces to end-user programming

- **Visual Agent Talk (VAT)**
  - representations of conditions, actions and rules as graphical objects
  - interface support (drag and drop) for end-user programming

Conclusions

- complex (software) systems should be regarded as **“living” entities** which are open and evolve

- the **seeding, evolutionary growth, reseeding (SER) model** is a feasible model for the evolutionary design of complex software systems

- complex (software) systems need to be **evolvable by their users**, not just by their developers

- these requirements create many interesting **research challenges** for
    - end-user modifiability
    - decentralized system development
    - new conceptualization of the WWW
        - culture changes in individuals (consumers → designers) and organizations