The Inculcation of Systems Thinking

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Inculcating Systems Thinking

- There are elements of systems thinking that are likely born, not made...
  - Those with the Myers-Briggs NT temperament (the “Rationals”) seem to predominate
- ...but (as is often the case) an education is necessary to turn aptitude into ability
- More than just teaching particular systems, we must educate *how to think* about systems
- But how do you teach wisdom?

Some Systems Themes

- Some themes seem to run across systems, and across domains:
  - The role of pathology in systems understanding
  - The duality between the abstract and the concrete
  - The expression of system value in terms of the ratio of price to performance
- By teaching these themes we can effect systems thinking
- But we need to expand on the themes to consider how best to teach them...

Systems Pathology

- Sufficiently complicated systems are not necessarily instructive when functional – systems can work by accident
- A pathological system, on the other hand, <u>always</u> has something to teach
- But there is a natural tendency to dismiss the pathological system as incompetence, aberration or an exercise to the reader
- Such systems are often dismissed *without* completely understanding the failure!

The Pathology Opportunity

- Systems are buildable/understandable because *abstraction* permits subsystems
- But the layering of abstractions can lend a false sense of simplicity...
- In a pathological system, the abstraction layering becomes violated in some way, and the complexity reveals itself
- This complexity is the mechanism of the system – diagnosing pathology presents a unique opportunity to understand it

Diagnosing Pathology

- Diagnosing a pathological system is most straightforward when pathology is *fatal*
- With fatal pathology, the final state is both *static* and *invalid*
- One proceeds backwards to find the transition from a valid to an invalid state
  - Where multiple transitions are possible, data from the final state is used to eliminate possible state transitions from consideration
  - Becomes challenging when there is insufficient data in the final state to eliminate possibilities

Non-Fatal Pathologies

- Pathology need *not* be fatal – a system can be logically correct, but so profoundly suboptimal as to be undesirable
- Non-fatal failure is often much more challenging to diagnose than fatal failure:
  - The state is both *dynamic* and *valid* – one does not have invalid states, but rather evolving symptoms
  - Can be very difficult to move from symptoms to underlying cause, especially when pathologies cascade (*Leventhal's Conundrum: given the hurricane, where is the butterfly?*)

Understanding Pathology

- In understanding many failed systems, one's thinking *shifts* to focus on pathology
- When conceiving a new system, one:
  - Considers the edge conditions, where a system's fatal failings lurk
  - Considers the diagnosis of fatal failure, and how to provide the richest possible (if invalid) state
  - Considers the diagnosis of non-fatal failure, and how to provide the most semantically meaningful dynamic instrumentation
  - Develops methodologies to verify a system as it's being developed

Teaching Pathology

- Systems pathology is best understood in synthetic systems of one's own design
- Courses teaching systems should have lab components wherever possible
  - Lab-built systems should be of sufficient complexity to allow students to experience the scope of pathology that exists in real-world systems
  - Students should be provided professional-grade tools; it is critical to know one's tools and their limitations
  - Lab-built systems should be expected to be flawless, and should be automatically verified

The Abstract/Concrete Duality

- *Abstraction* is absolutely essential for understanding and designing systems
- But the development of abstraction can be too powerful a tool – if one loses the concrete, one develops abstractions that no longer correspond to reality
- Mastering this *duality* between the abstract and the concrete is the essence of systems thinking

Maintaining the Duality

- One cannot focus exclusively on either the abstract or the concrete – one needs both
- To maintain the duality, one must *oscillate* between the abstract and the concrete, using each to reinforce the other
  - When dealing with the abstract, use the concrete to verify or revise
  - When dealing with the concrete, use the abstract to motivate and refactor
- This oscillation requires a limber mind – but it is the essence of systems innovation

Teaching the Duality

- Education is traditionally very good at the abstract, but the concrete can be more of a challenge...
- ...so systems courses need to pay special attention to the concrete:
  - Systems lectures should present concepts, with in-class demonstrations when possible
  - Systems labs should be sufficiently expansive to incorporate many concrete details
  - Wherever possible, “real-world” examples should be used, e.g. guest speakers describing actual systems

Ratio of Price to Performance

- System performance does not exist in a vacuum; it is inextricably linked to *price*
- The ratio of a system's price to its performance is the expression of its *value*
- The ratio expresses the relationship of a system with a larger one: an economic system that reflects choices given scarcity

Defining the Ratio

- Performance and price should both be defined broadly
  - Performance is the work done by the system
  - Price is the explicit *and* implicit cost of the system
- Many systems fail for either poorly defining or ignoring price/performance:
  - Some are lured by highest *absolute* performance
  - Some cling to the *wrong notion* of performance
  - Some overlook substantial *implicit costs*

The Ratio and Innovation

- One can harness the power of the price-to-performance ratio by innovating *in terms* of the ratio
- A system that effects a sufficiently large improvement in price/performance is called a *disrupting innovation*
  - Nearly always happens when less performance is delivered at *much less* cost
  - Has happened often in history – it is the systems embodiment of Schumpeter's “creative destruction”

Teaching the Ratio

- To inculcate a sense of the relationship of price to performance, we must teach – at some level – the *economics* of systems
- This is perhaps most easily done by looking at the history of technology, which is littered with economic carcasses
- Might make an appropriate “light” senior seminar course (with technical, lab-oriented systems courses as prerequisites)

Recommended Reading/Viewing

- Systems pathology
  - > *When Technology Fails* by Neil Schlager
  - > *NOVA* circa 1993 on COPA (Panama) 737 crash
  - > *Crash Files of the NTSB*, esp. “Disaster on Duffy Street”
- The abstract/concrete duality
  - > *The Education of Henry Adams* by Henry Adams
  - > *Skunk Works* by Ben Rich
- Importance of price/performance
  - > *The Innovator's Dilemma* by Clayton Christensen
  - > *Mastering the Dynamics of Innovation* by J. Utterback
  - > *The Economist, The Wall Street Journal*

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