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# A Note on Computer Systems Research



# Computer Systems Research

- What is computer systems research?
  - Dealing with everything between hardware and applications
- The capstone of all the computer science principles:
  - Operating systems
  - Computer architecture
  - Computer networks
  - Compilers
  - Programming languages
  - Databases
  - Security
  - Data structures and algorithms, ...

# Computer Systems: Area

- Parallel and distributed systems
- Embedded systems
- Database management systems
- Networked systems
- Storage systems
- Cloud computing
- Mobile computing
- Ubiquitous or pervasive computing, IoT
- CPS (Cyber-Physical Systems)
- Blockchain
- Machine learning
- ... and you name it!

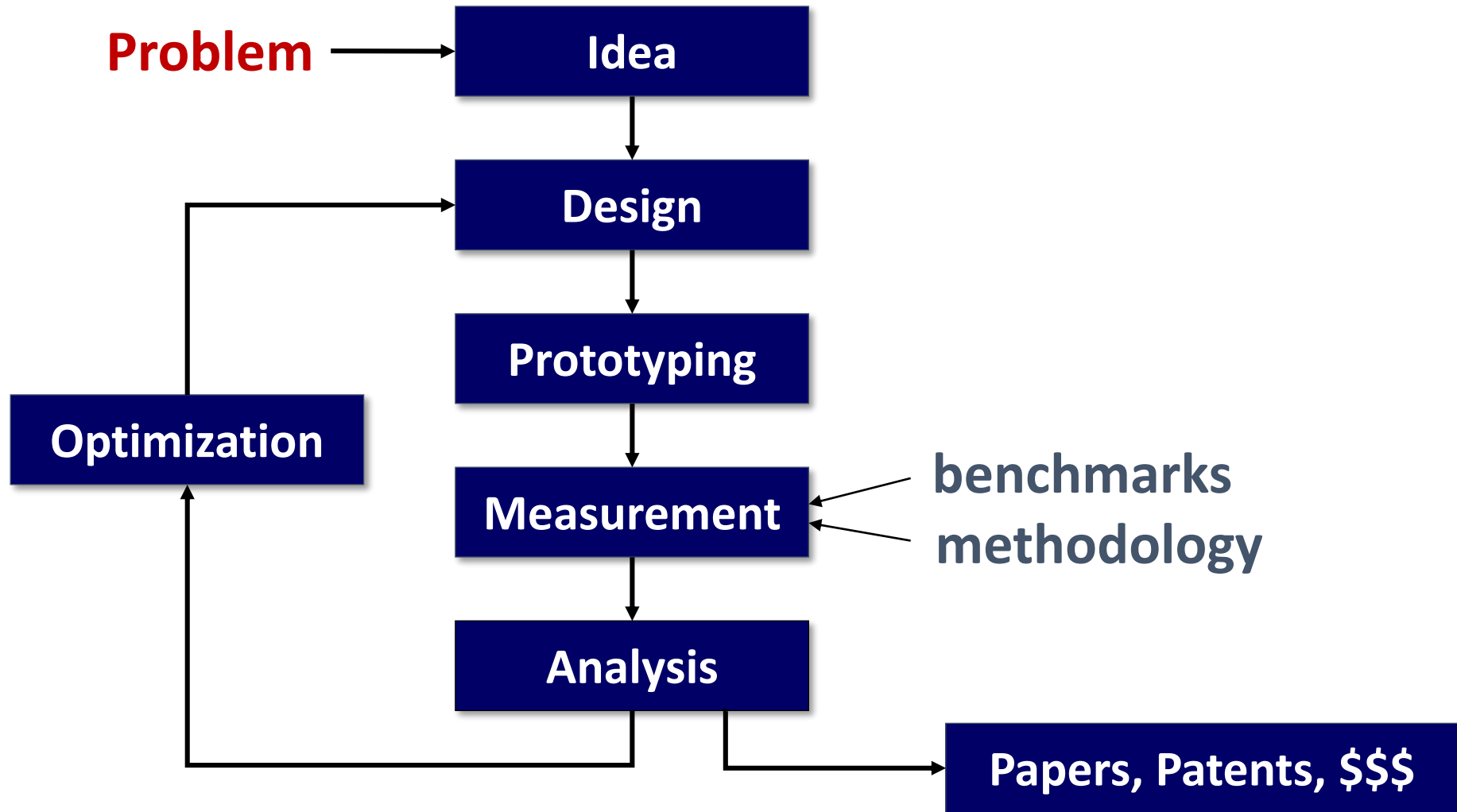
# Computer Systems: Characteristics

- Designing computer systems is very different from designing an algorithm
- The external requirement is less precisely defined, more complex, and more subject to change
- The system has much more internal structure, hence many internal interfaces
- The measure of success is much less clear

# Challenges

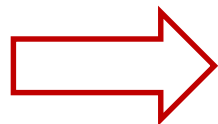
- Large system is difficult to understand or build
- There are not necessarily any right answers
  - There is a sea of possibilities
  - Unclear about how one choice will limit his freedom to make other choices, or affect the size and performance of the entire system
- No one can tell you with certainty that you are right
  - The best way we can do is to avoid choosing a terrible way
  - The art of trade-offs
- You are never done
  - The last 10% to perfection typically consumes 80% of the effort
  - You don't know if the resulting system is perfect or not

# Systems Research Cycles



# Getting Idea

- Identify a problem/phenomenon in the current systems
  - Physical memories are small
  - CPU is getting faster but I/O is NOT that much
  - Number of cores is increasing, ...
- The world is changing (always):
  - New services: WWW, Web services, P2P, Grid, MMORPG, Cloud, XaaS, ...
  - New applications: DB, Java, Games, Big Data, Machine learning, Blockchain, ...
  - New environments: Wireless, Mobile, Ad-hoc, Battery-powered, VR, AR, 5G, ...
  - New architecture/devices: Multi-cores, NVDIMM, Flash, RDMA, GPU, FPGA, ...



**Add a functionality**

**Enhance performance, reliability, or energy-efficiency**

**Develop a new system**

# Getting Idea: Some Suggestions

- Have a broad spectrum of knowledge
  - Read widely
  - Participate in seminars
  - Don't stick to your \*field\* (Bad Career Move #1)
- Know the state-of-the-art technology
  - See what other people are doing
- Stay tuned for emerging technologies and predict their implications
- Be a team player; discuss with others
- There is no free lunch
  - Practice solving problems and building systems whenever you have a chance



# Design

- **Functionality**
  - Does it work?
- **Speed**
  - Is it fast enough?
- **Fault-tolerance**
  - Does it keep working?

# Design: Lampson's Hints

Why?	<i>Functionality</i> Does it work?	<i>Speed</i> Is it fast enough?	<i>Fault-tolerance</i> Does it keep working?
<b>Where?</b>			
<i>Completeness</i>	Separate normal and worst case	Shed load End-to-end Safety first	End-to-end
<i>Interface</i>	Do one thing well: Don't generalize Get it right Don't hide power Use procedure arguments Leave it to the client Keep basic interfaces stable Keep a place to stand	Make it fast Split resources Static analysis Dynamic translation	End-to-end Log updates Make actions atomic
<i>Implementation</i>	Plan to throw one away Keep secrets Use a good idea again Divide and conquer	Cache answers Use hints Use brute force Compute in background Batch processing	Make actions atomic Use hints

Source: B. Lampson, "Hints for Computer Systems Design," SOSP, 1983.

# Design: Policy vs. Mechanism

## ■ Policy

- *What* should be done?
- Policy decisions must be made for all resource allocation and scheduling problems
- e.g. CPU scheduling: scheduling algorithm, quantum size, priority, etc.

## ■ Mechanism

- *How* to do something?
- The tool for implementing a set of policies
- e.g. CPU scheduling: dispatcher for low-level context switching, priority queues, etc.
- e.g. X-windows implement “mechanism, not policy”

# Design: Separating Policy from Mechanism

- A key principle in operating system design
- Policies are likely to change depending on workloads, and also across places or over time
  - Each change in policy would require a change in the underlying mechanism
- A general mechanism, separated from policy, is more desirable
  - A change in policy would then require redefinition of only certain parameters of the system instead of resulting in a change in the mechanism
  - It is possible to experiment with new policy without breaking mechanisms

# Design: Policy / Mechanism Benefits

- Allows to build a more modular system
  - Only need to port mechanisms
- Enables extensible systems
  - Microkernel only implements a basic set of policy free primitives
  - More advanced mechanisms and policies are added via user-created kernel modules or via user programs themselves
- One can design a kernel that allows processes to download their ideal policies directly into the OS

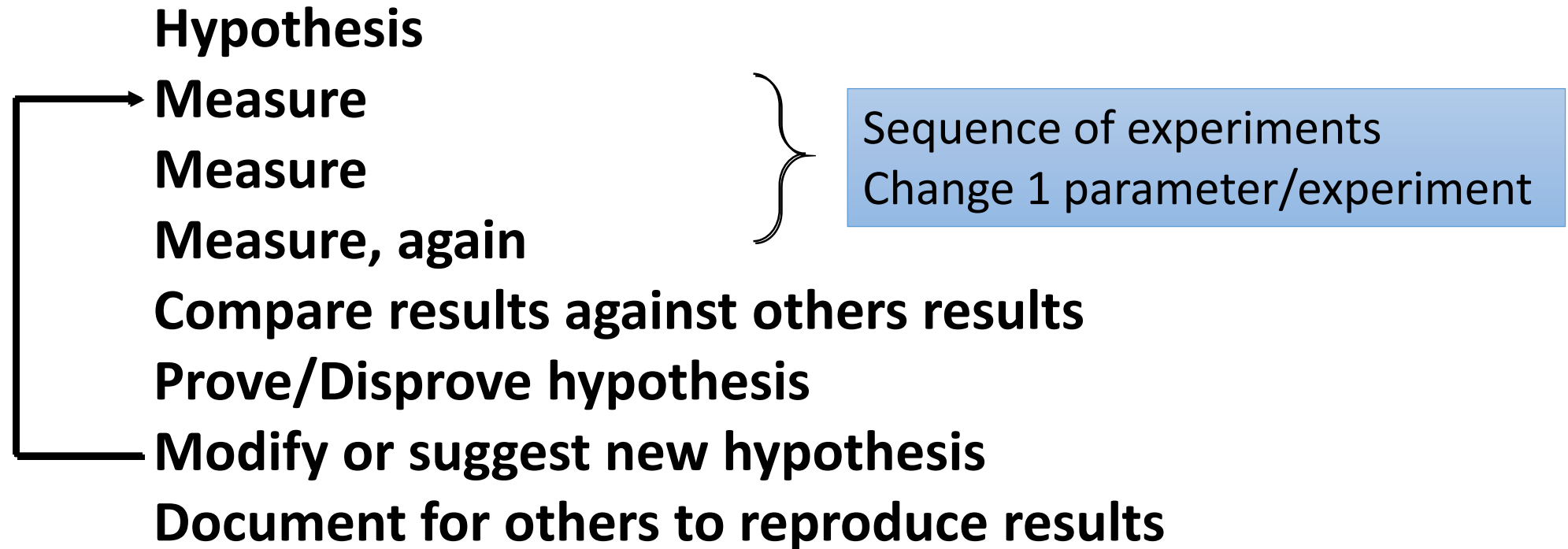
# Design: Some Suggestions

- Ask *why* you are doing this
  - Define your problem, goals, and metrics first
  - And then, ask Who? When? What? How?
- List the expected benefits and costs
  - BEFORE any experiments
  - Determine the graphs you would like to see
- Think of any other way you can do better
  - Implementations are expensive; take enough time on design
- Again, be a team player; review your design with others
  - Two heads are better than one

# Evaluation: Methodologies

- Use analytical investigations
  - Probably too many assumptions
  - Need to inject real parameters... How to obtain them?
- Use simulations
  - OK if you use the well-known simulator, or open-source your simulator
  - Need to prove your model is correct; run sanity checking experiments to which you know the answer
- Gather traces from real systems
  - Traces are much easier to deal with
- Instrument or modify existing systems: Hard...
- Build prototypes: Harder...

# Evaluation: Use Scientific Method



- Use your intuition to *ask* questions, not *answer* them
- What's your metric?



# Writing a Research Paper (I)

## ■ Abstract

- Introduce area
- State problem
- Summarize conclusions (be quantitative)

## ■ Introduction

- Complete description of problem
- State more detailed results
- Short summary of what's have been done
- Roadmap of the paper

# Writing a Research Paper (2)

## ■ Previous work

- Do a thorough literature search (from 60's)
- Neither more nor less list of references
- Relate your work to existing work
- Demonstrate how your work fits in to the grand scheme of things

## ■ Design & Implementation

- Do describe your research
- Be thorough, but concise
- Clarify why you made such design decisions

# Writing a Research Paper (3)

## ■ Evaluation

- Describe experimental setup (both hardware and software)
- Explain your methodologies
- Explain expected results, reasons for such expectation
- Explain surprising difference
- Visual presentation of data

## ■ Conclusions

- State results again
- State significance of results
- Tell people what they should have learned

# Writing a Research Paper (4)

## ■ Future work

- What questions still remain
- What new questions have arisen
- How can your work be extended

## ■ General tips

- Spell check: very important
- Grammar check: very difficult for us, but try
- Style check: passive voice, plural, he/she, ...
- **Consistency** in figures, graphs, references, etc.
- As research is going on, start writing and write often: very important
- Let the paper sit for a few days before proofreading
- Read many papers!

# Evaluation Criteria for Systems Research

- Importance of a problem
- Soundness of assumptions
- Originality and novelty of ideas
- Availability of real implementations
- Exploration of alternative design choices
- Value of lessons learned

# Systems Research is Multifaceted

## ■ Science

- Discover truth by scientific methods
- Identify the effects and limitations of computer artifacts on the physical world

## ■ Engineering

- Achieve a solution that works for a particular problem
- Develop “good enough” heuristics

## ■ Art

- Elegance, beauty, and simplicity
- Make complex ideas more palatable or more comprehensible

*Source: A. Brown et al., “The Many Faces of Systems Research – And How to Evaluate Them,” HotOS, 2005.*

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