CSC 595 - Research Skills

Great Researchers

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*For the structure and some content/“math”, credit goes to
Nick Feamster and Alex Gray: https://noise-lab.net/research-course/

Upcoming things to submit

- Project - Initial Report (this is really light weight…) - Due today, September 23rd
  - Submit title for your project and name of the advising faculty member for your project
- Assignment 1 - Recognizing Great Ideas - Due this Thursday, September 25th
  - **Really important: only select papers from *recent conferences* (a few people asked)**
  - It's important that you take a careful look through a conference proceedings (at least a good fraction of it). Don't just have your advisor select papers. That defeats 50% of the point of this assignment.

What does *great* mean?

- Think someone who performs at the level of an Olympic athlete, but for research
- If you train to escape Earth's orbit, even if you don't reach that goal, you should at least reach the stratosphere
- The point of this course is how to do great research, so this lecture is about what it takes to be a great researcher

How will I become a great researcher?

- It isn't clear how to simply "be great" (unless you're Feynman)
- Let's talk about a plan
- We'll form a cartoon mathematical model of the elements of great researchers
- We'll look at which parameters we have control over and what effect they (and other, less tunable parameters) have on **Greatness**
- We'll then consider traits of great researchers. Remember that these are basically Olympic athletes. The path might look difficult, but let's aim as high as we can.
    - You may not like hearing this

A (cartoon) mathematical theory of great research

- Intuitively, **Greatness** of a result measures how ***surprising*** a result is
- What makes a result of a given **Significance** surprising?
  A low probability of seeing a new result of that **Significance**.
- **Surprisingness** of a result is $\frac{1}{\Pr(\text{Significance})}$
  - For low probability results, this is roughly the odds *against*
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- Connection to the field of Information Theory:
  - if an event occurs with probability p, the "surprisal" of the event is $\log\left(\frac{1}{p}\right)$
- So, $\text{Greatness} = \dfrac{1}{\Pr(\text{Significance})}$ we only want results of *high* **Significance**…

What makes a result Significant?

Gray's First Law of Research

$$\text{Significance} = \text{Significance}(\text{Problem}) \times \text{Significance}(\text{Solution})$$

- **Significance** of the **Problem** and **Significance** of the **Solution** both matter
- Which ones is harder to get? Which one do we have less training for?

How do I get a Significance? (either a problem or solution)

- How about: $\text{Significance} \propto \text{Ability} \propto \text{Brains}$

- Hmm… but how does effort (time spent) enter the picture? And is **Ability** everything? And is **Ability** really just **Brains**?

Let's decompose Significance and see how Time Spent enters the picture

$$\text{Significance} = \text{LeapSize}^{\text{NumLeaps}}$$

$$\text{LeapSize} \propto \text{Ability} \propto \text{Brains}$$

$$\text{NumLeaps} \propto \text{TimePutIntoProblem}$$

- Let us assume **Ability > 1**. Valid for grad students (can fail to hold for undergrads…)
- OK, so we accounted for **Time** spent on a problem.
- Let's dig more into **Ability**. Maybe it depends on more than just **Brains**?

Knowledge and Skill

$$\text{Ability} \propto \text{Brains} \times \text{Skill} \times \text{Knowledge}$$

- **Brains** = raw CPU speed (HPU = human processing unit speed?)
- **Skill** = techniques (e.g., visual design, statistics), experience solving problems of relevant type
- **Knowledge** = written knowledge (textbooks, papers)
- **Brains** aren't everything. With the same brain speed, having more skills can get results faster. And having more knowledge allows more concepts (similar to memoization, but with *understanding* too).

How can I increase Knowledge and Skill?

$$\text{Knowledge} \propto \text{TimeGainingKnowledge}$$

$$\text{Skill} \propto \text{TimeGainingSkill}$$

- Improving anything (knowledge, skill, getting more leaps) requires time
- **TimeGainingKnowledge** = classes, reading textbooks and papers
- **TimeGainingSkill** = classes, working on projects that hone a skill projects
- **TotalTime = TimeGainingKnowledge + TimeGainingSkill + TimePutIntoProblem**
- It seems that a lot of **Time** is needed. It's important to find a good way to divide time…
  … and using a block of time more efficiently means supercharging the "increasing" process

Interlude: Time Log

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- Mini-Assignment 2 is now released. You'll do a Time Log
- Why a Time Log?
  - **Time** is a resource that, if used well, can give exponential gains to research productivity
  - Interruptions during planned work periods, unplanned work, frequent context switches can all have disastrous effects on productivity
  - Hard to observe what is going on without a Time Log

Where were we?

Recall: How can I increase Knowledge and Skill?

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I’ll need LOTS of Knowledge and Skill

- BIG problems can make contact with several areas…
- … and good solutions may require DEEP knowledge in several areas
- Need lots of knowledge to form a mental map of what is known/resolved and what is unknown/open
- BIG solutions requires lots of experience (to get Skill) applying various solutions to various problems
    - Potential for transfer

The value of Knowledge of different areas

- Fire (Thermodynamics) + Wheel (Mechanics) = Automobile
- Radio Engineering + Astronomy = Radio Astronomy *(Karl Jansky)*
- Statistics + Differential Geometry = Information Geometry *(C. R. Rao, Shun-Ichi Amari)*
- Physics + Riemannian Geometry = General Theory of Relativity *(Einstein)*
- Neuroscience + Computer Science = Artificial Neural Network *(McCulloch and Pitts)*

Novelty

- OK, it seems that **Ability** is important, and there is a rough idea of how to increase it
- Does **LeapSize** depend on anything else? How about **Novelty**?

$$\text{LeapSize} \propto \text{Ability} \times \text{Novelty}$$

$$\text{Novelty} \propto \text{Creativity}$$

- Is **Creativity** determined by Nature? In part, yes…
- …but there are learnable techniques for creative thinking as well. Stay tuned for a later lecture!

Knowledge from Other People

$$\text{Knowledge} \propto \text{TimeSoloGainingKnowledge} + \text{TimeCommunicating}$$

- Not all **Knowledge** is written down
- **Knowledge** is also distributed across people

Clarity

$$\text{Knowledge} \propto \text{TimeSoloGainingKnowledge} + \text{TimeCommunicating} \times \text{Clarity}$$

- What about the effect of **Clarity** (of communication)?
- Higher **Clarity** means the same amount of **TimeCommunicating** gives more **Knowledge**
- Also, **Clarity** is a special type of skill!

Novelty from my own Connections

$$\text{Novelty} \propto \text{Creativity} \times \text{NumConnections}$$

$$\begin{aligned}\text{NumConnections} &\propto \text{Knowledge}_1 \times \ldots \times \text{Knowledge}_{\text{NumAreas}} \\ &\propto \text{Knowledge}^{\text{NumAreas}}\end{aligned}$$

- We take some mathematical license on the last line, but it roughly works if **Knowledge** per area is much larger than 1
- There is an *exponential* payoff to having average amount of knowledge in many areas

Novelty from a Teams' Connections

$$\text{Novelty} \propto \text{Creativity} \times \text{NumConnections}$$

$$\begin{aligned}\text{NumConnections} &\propto \text{Knowledge}_1 \times \ldots \times \text{Knowledge}_{\text{NumAreas}} \\ &\propto \text{Knowledge}^{\text{NumAreas}}\end{aligned}$$

- A **Team** of diverse experts collectively has knowledge of multiple areas
- The connections they find can be valuable. Yet, the deepest connections usually come from a single brain that knows many areas (faster communication within one brain)

Guts

- So far, we covered **Brains**, **Creativity**, **Clarity**, **Time Spent**, choice of **Number of Areas**
- What else is there? **GUTS!**
- Guts means courage, bravery, fearlessness (unafraid to be alone, unafraid to be wrong), willingness to chart your own course
- High **Guts** means being *risk-seeking (*not *risk-averse*)
- Where does **Guts** enter the picture?

Guts

$$\text{LeapSize} \propto \text{Ability} \times \text{Novelty} \times \text{Guts}$$

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Greatness and Significance

$$\Pr(\text{Significance}) \propto e^{-\text{Significance}^2}$$

$$\text{Greatness} = \frac{1}{\Pr(\text{Significance})} \propto e^{\text{Significance}^2}$$

- We assume a Gaussian model of **Significance** (yes, a bit weird, but even Exponential model gives qualitatively similar conclusions)

- **Greatness** is *exponential* in **Significance**. A small increase in **Significance** goes a long way!

What are the fundamental variables?

There are variables given to us by Nature:

- Brains, Guts

And variables that are largely set by Nature but that we can improve like skills:

- Creativity, Clarity

And variables that are under our direct control:

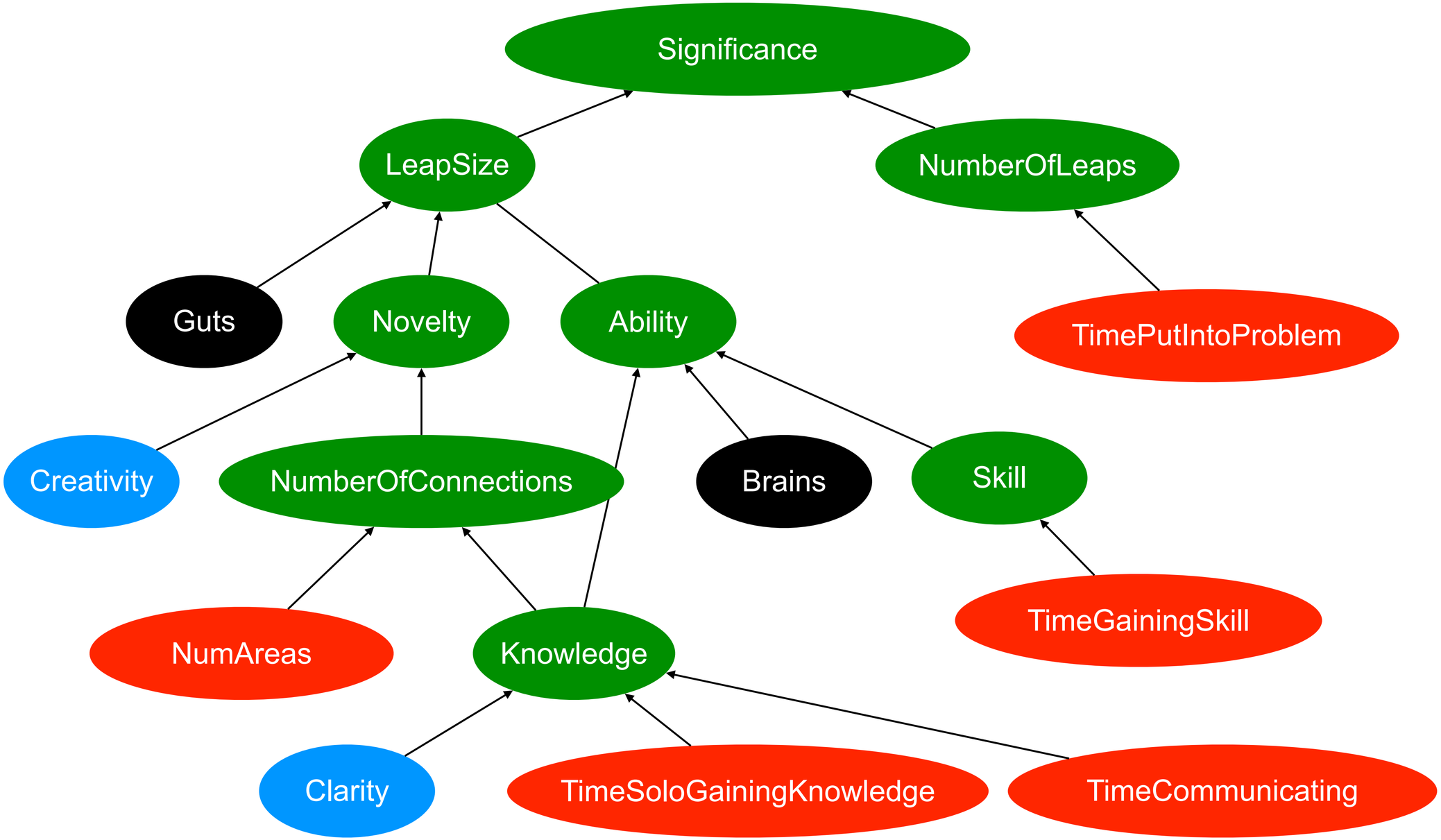
- TotalTimeSpent, NumberOfAreas

Our Model of Significance

$$\text{Significance} \propto \left(\begin{array}{l} \text{Brains} \\ \times \text{Guts} \\ \times \text{Creativity} \\ \times (\text{TimeSoloGainingKnowledge} + \text{TimeCommunicating} \times \text{Clarity})^{\text{NumAreas}+1} \\ \times \text{TimeGainingSkill} \end{array} \right)^{\text{TimePutIntoProblem}}$$

- Primitives in **black** are not under our control
- Primitives in blue are partially fixed but can be improved to some extent
- Primitives in red are fully under our control!
- Tuning the red variables can lead to ***massive*** increases to **Significance**

The picture that emerges



What about *me*?

Can *I* do great research?

What are the traits of people that do great research?

Talent

People who do great research…

- Have at least average **Talent** (**Brains**, **Guts**, **Creativity**)
  - Remember that **Creativity** is a skill to some extent
  - Also, to some extent **Brains** can be boosted (e.g., via exercise)
  - If someone is low on one aspect but paired with the right person, together they might do good (or even great) research. Think: famous dynamic duos of researchers

Curiosity

People who do great research…

- Exploring many areas
- Ask lots of questions
- Probe for knowledge in less-explored places (independent thinkers)
- In some sense, might be a bit weird; in the “tail of the distribution”

Knowledge

People who do great research…

- Acquire *lots* of knowledge
- And do so fearlessly
  - Get knowledge from *anyone*
  - *G*et knowledge from *anything* (“scary” books, intimidating papers)

Self-Tuning

People who do great research…

- Self-monitor their weaknesses and…
- … Learn to learn (improve their internal “algorithm”)
- Form good habits
- Learn how to stay motivated, be healthy, and be happy

Skepticism

People who do great research…

- Don’t just believe stuff… they think critically
- Don’t just follow trends and leaders of the field
- In the presence of conflicting ideas (“noise”), think critically to find the truth (“signal”)

Guts

People who do great research…

- Are prepared to be wrong
- Seek out the “big” problems
- Are ready to be revolutionaries

Work

People who do great research…

- Work a *lot*
- Work efficiently, getting more out of each block of time and minimizing interruptions

Recall: “compounding interest” and the exponential payoff of spending more time

Persistence

People who do great research…

- Relentlessly attack a problem
- Live and breathe their problems

Communication

People who do great research…

- Communicate well, giving good talks and having good one-on-one conversations
- Explain problems and solutions clearly and efficiently, tuned to the specific audience
- Are good story tellers
- Don’t just try to “look good” (appear smart), but focus on the audience’s understanding
- Formulate questions clearly

Social

People who do great research…

- Are generous (with time, inviting others to collaborate)
    - Leads to others being generous in return
- Can work efficiently in a team
- Iron out personality issues (impatience, anger, ego, arrogance, etc.)

Advice

- Remember that if you shoot for greatness, you'll at least be pretty good
- So, just aim as high as you can
- Take every project seriously. Don't half-ass stuff (if you aren't giving your all, then why bother?)
    - Remember that part of working on a project is honing skills. So, sometimes warm-up projects (not interesting to others, but useful for you) can super-charge your later progress!
- Confidence goes a long way. Visualize who you wish you were, not who you are. Think of what that person would do. What is their process like. Can you adopt that process?