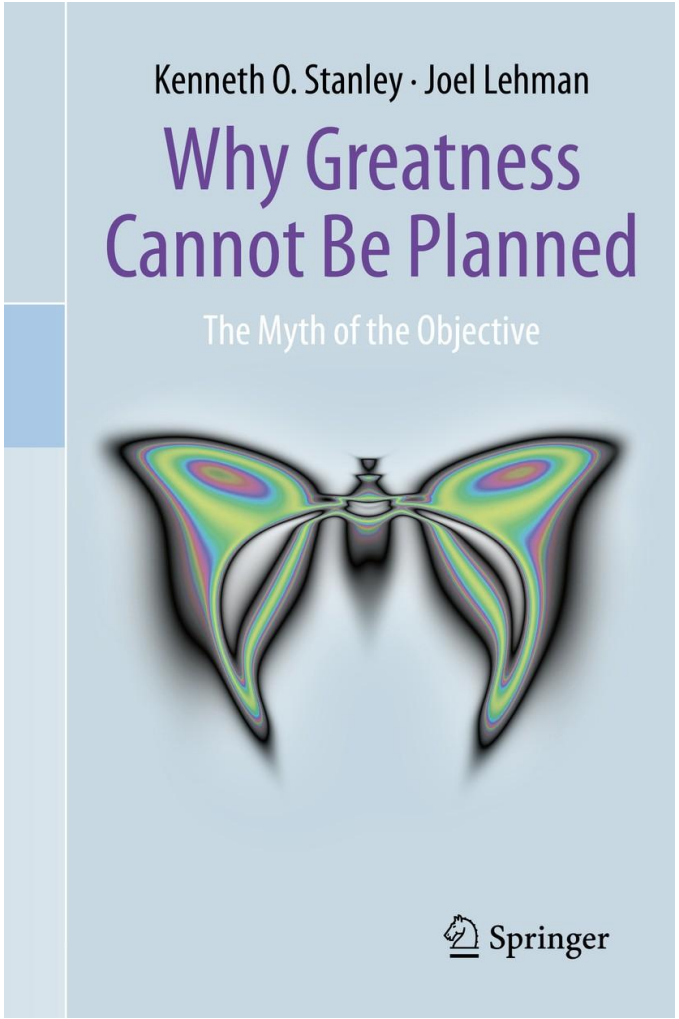


Why Greatness cannot be Planned

Kenneth Stanley & Joel Lehman

Tessellate Book Club
Judy King Yi CHO
1/10/24

Main Question: How Do Breakthrough Innovations Occur?

1. PicBreeder Experiment
2. The Strategy: No objectives (Open-endedness), Novelty Search, Stepping stone collector
3. Applications of this strategy
    a. In Research Process
    b. In Synthetic Biology
    c. In Life, Social, Entrepenurship…

The Authors

Previously :CEO, Maven
Open-Endedness Team Leader at OpenAI
Head of Core AI Research at Uber AI
Professor in Computer Science at
University of Central Florida

Inventor (with many distinguished colleagues) of NeuroEvolution of Augmenting Topologies (NEAT), compositional pattern producing networks (CPPNs), novelty search (NS)....

https://www.kenstanley.net/home

Kenneth O. Stanley

http://joellehman.com/

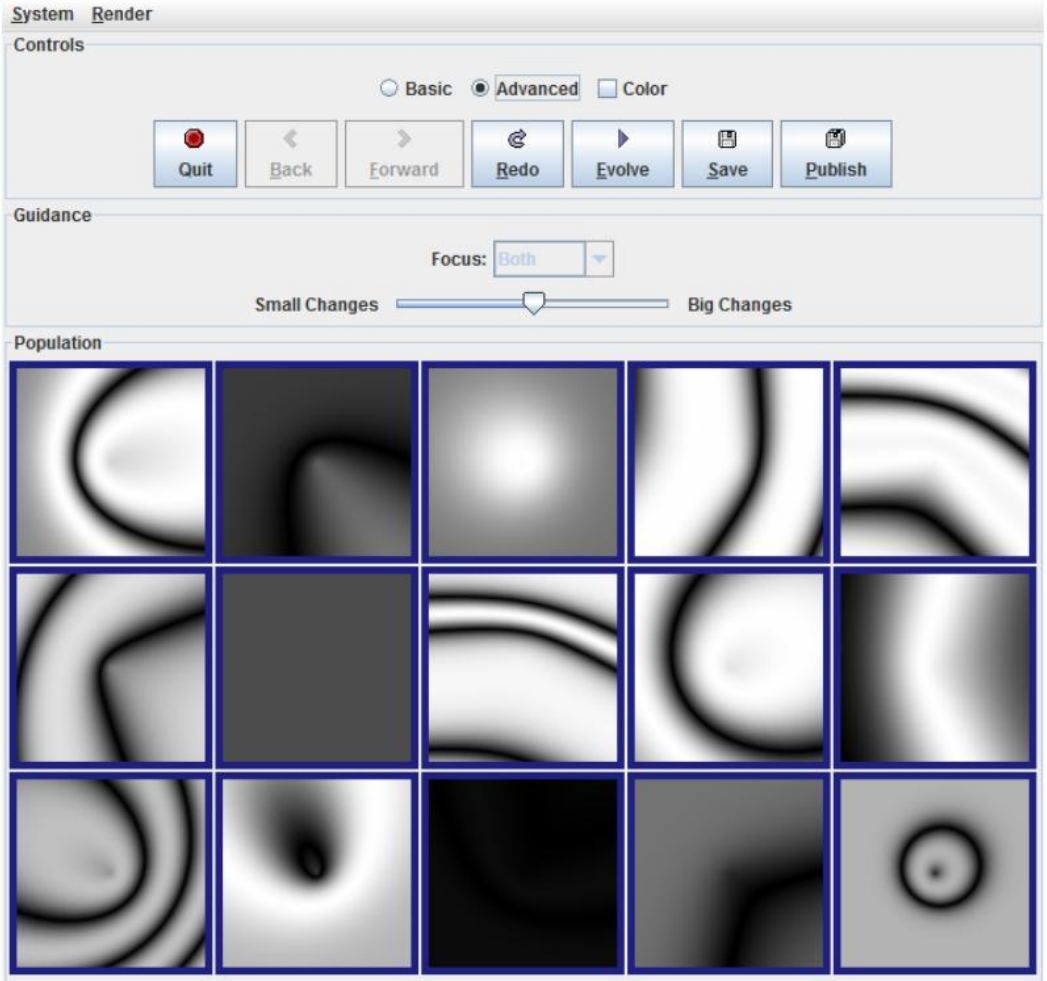
Joel Lehman

The paper (2008) The Book (2015)

Picbreeder: Evolving Pictures Collaboratively Online

Jimmy Secretan, Nicholas Beato, David B. D'Ambrosio, Adelein Rodriguez, Adam Campbell, and Kenneth O. Stanley
School of Electrical Engineering and Computer Science
University of Central Florida, Orlando, FL 32816-2362

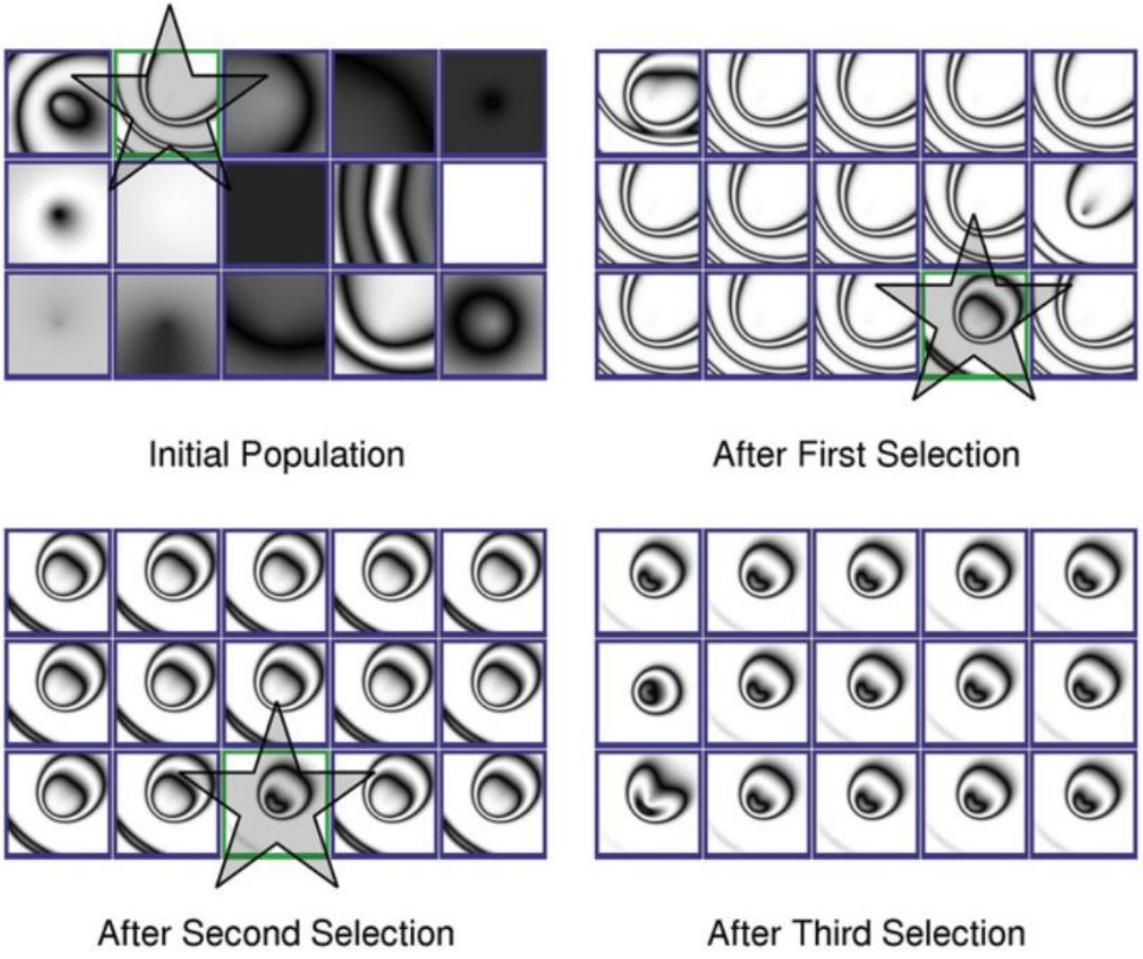
The PicBreeder Experiment: How it works?



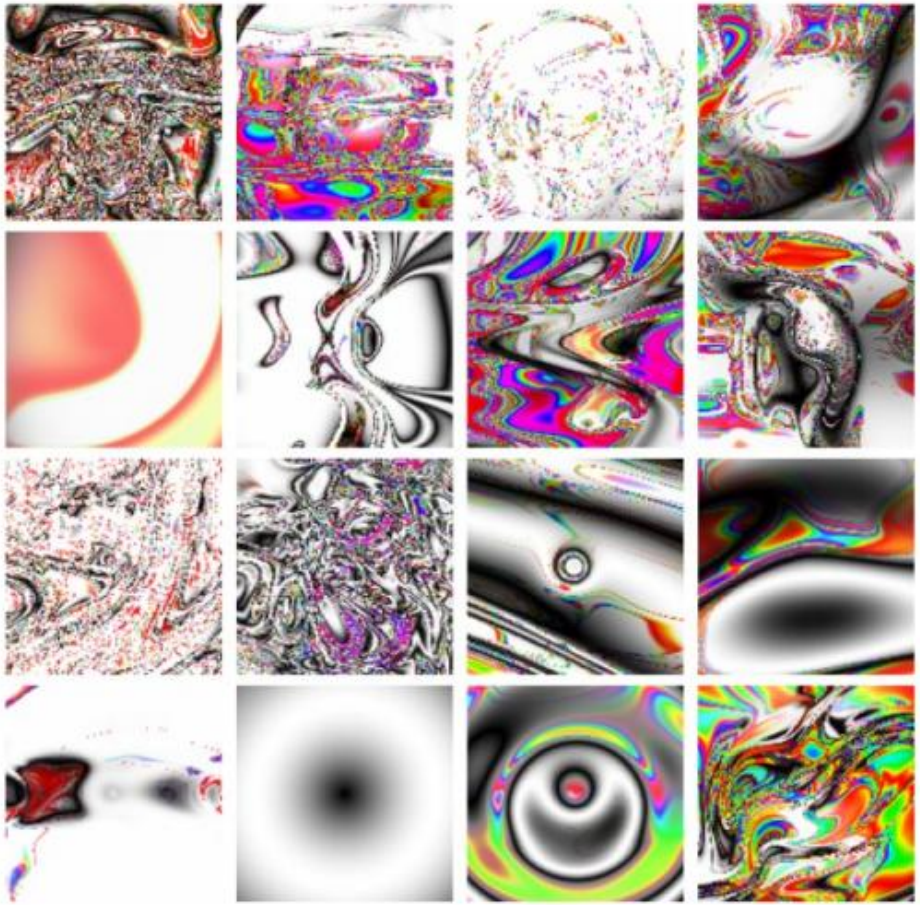
- Crowd-sourced picture-breeding website
- 7 years of operation (started since 2007)
- Almost 10,000 evolved images (lineages)
- Over 1,000 users
- NEAT Algorithm (NeuroEvolution of Augmenting Topologies)
- Pattern produced by CPPNs (Compositional Pattern Producing Network)

(Secretan J et al., 2008, 2011)

The PicBreeder: How it works?

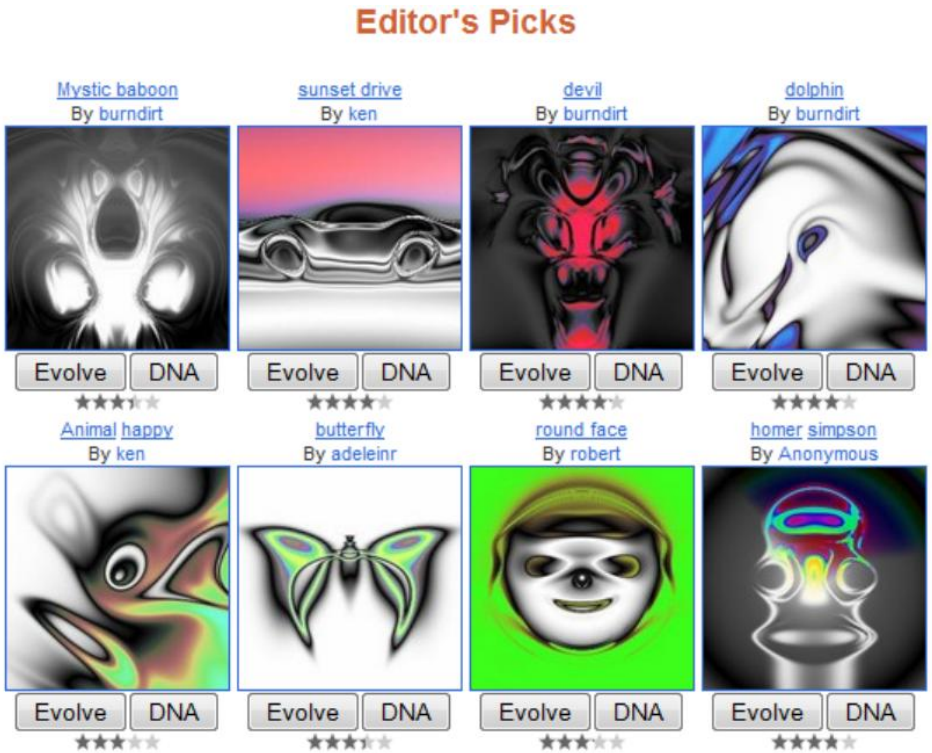


Most published images looks like these



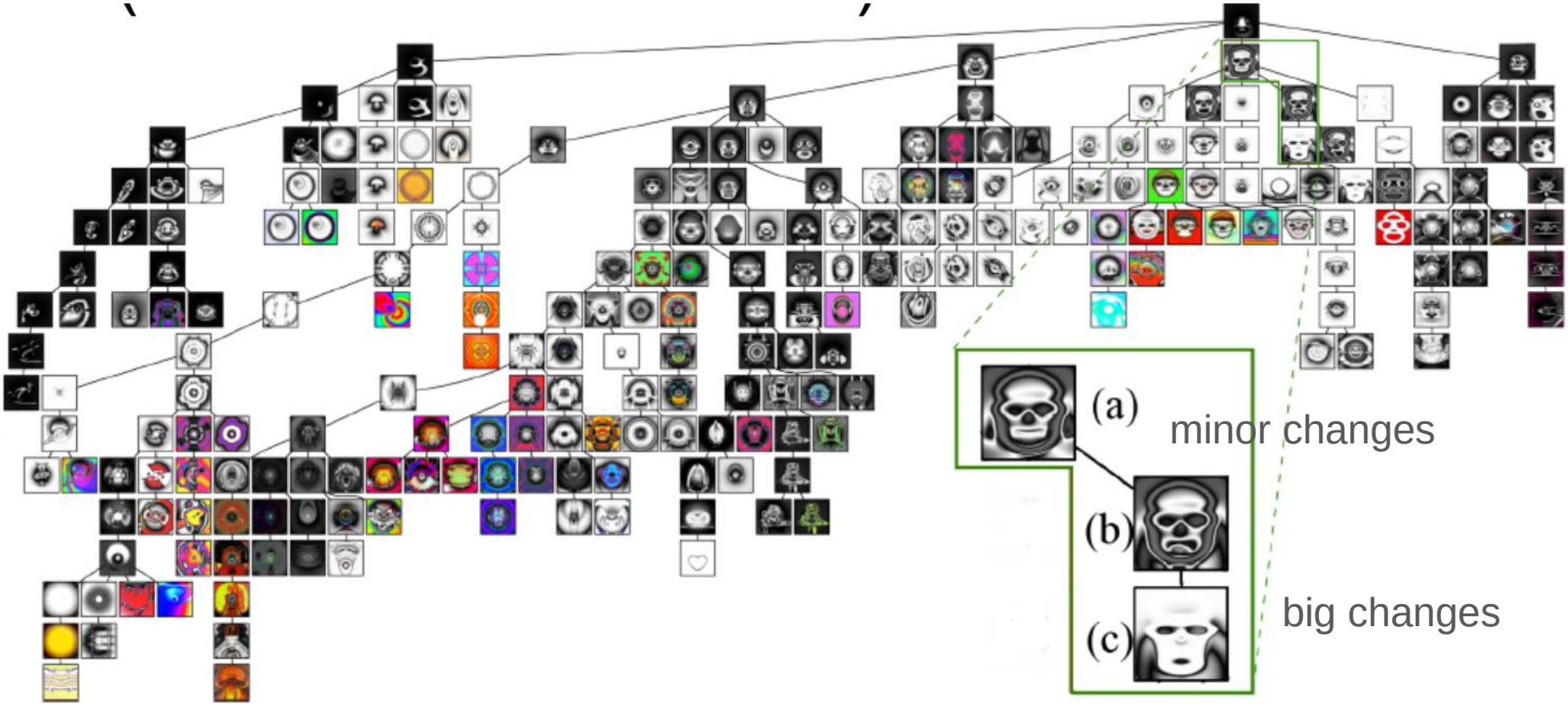
Discoveries by Picbreeder users (100% evolved)

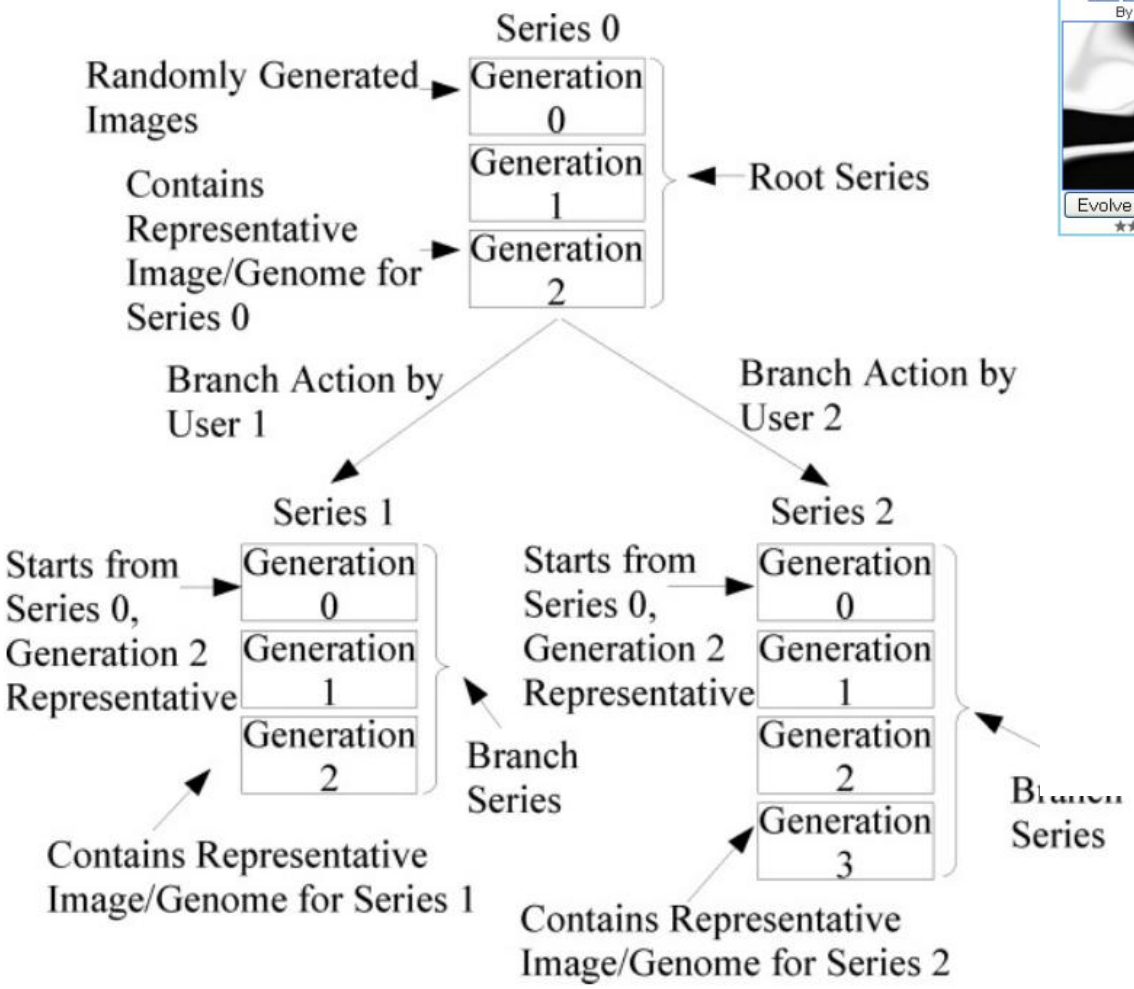
Important: Branching from existing discoveries



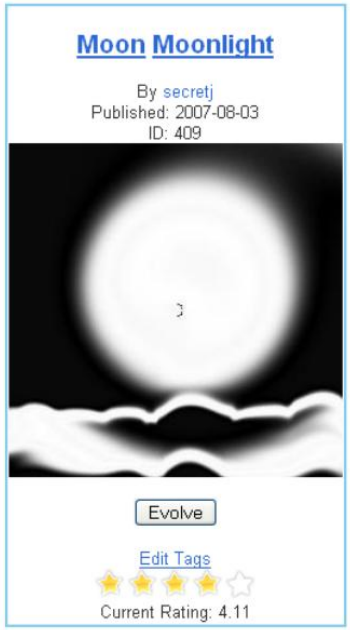
https://wiki.santafe.edu/images/3/34/Stanley_innovation_workshop14.pdf

Phylogenetic Tree of discoveries (from 30 users)




Series 0
Randomly Generated Images
Generation 0
Generation 1
Generation 2
Root Series
Contains Representative Image/Genome for Series 0
Branch Action by User 1
Branch Action by User 2
Series 1
Series 2
Starts from Series 0, Generation 2 Representative
Generation 0
Generation 1
Generation 2
Branch Series
Starts from Series 0, Generation 2 Representative
Generation 0
Generation 1
Generation 2
Generation 3
Branch Series
Contains Representative Image/Genome for Series 1
Contains Representative Image/Genome for Series 2


Parent:
hand palm offering
By entity
Evolve
Details


Moon Moonlight
By secretj
Published: 2007-08-03
ID: 409
Evolve
Edit Tags
Current Rating: 4.11

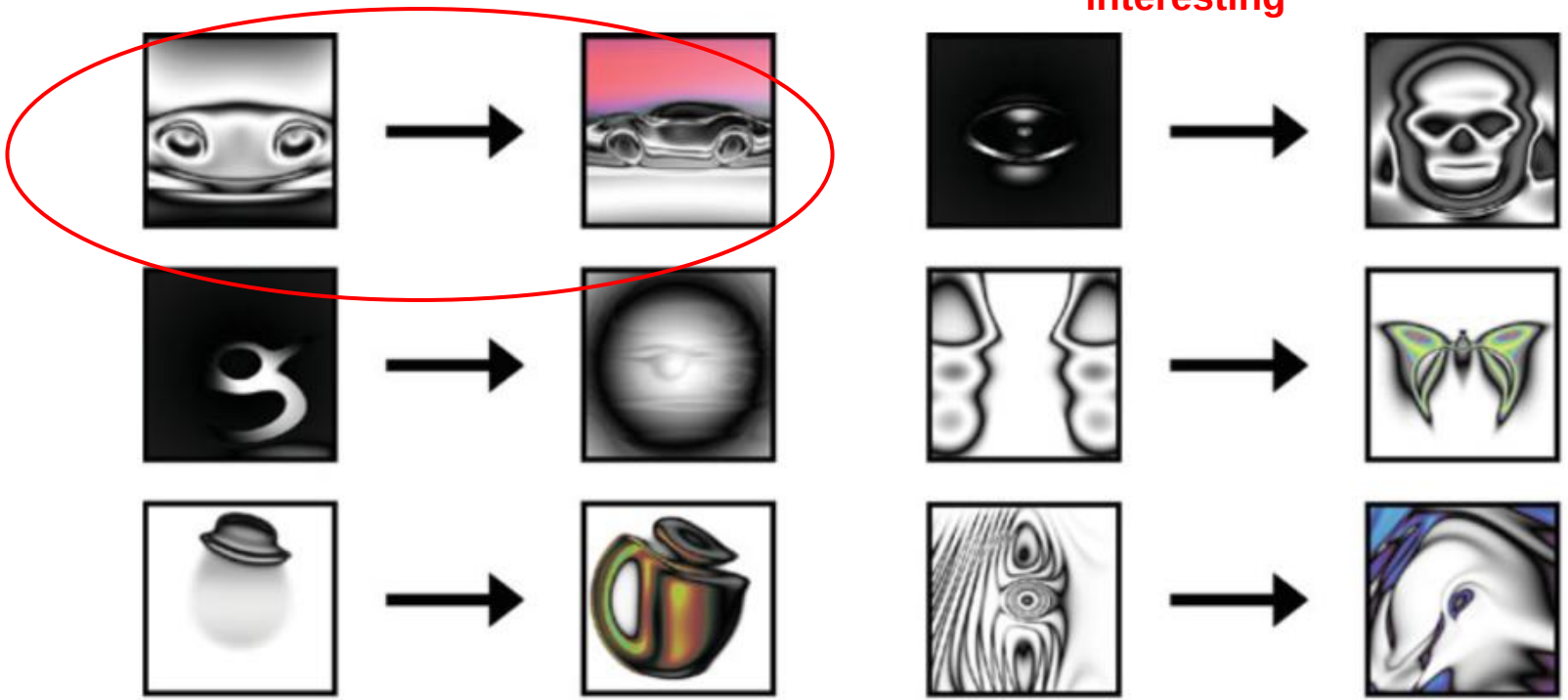

Children:
man standing silhouet...
By entity
Evolve
Details
mushroom cloud bomb
By ken
Evolve
Details
Not enough ratings.
clouds sun
By ken
Evolve
Details
Not enough ratings.

Stepping Stone to new discoveries

Insight 1: Stepping stone almost never resemble the final product!

Insight 2: Stepping stone looks interesting

alien face is a stepping stone to Car



"You can only find things by not looking for them"

How about trying to re-breed these from scratch?

Re-Breed with the same algorithm, but only pick the one that's closely resemble to the target images (Objective-based search)

74 generations from user branching

90 generations

Brian G. Woolley et al., 2011

Results from objective-based re-breeding

non-objective

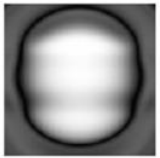
gen 74

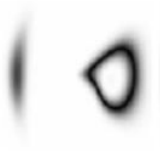
gen 90

ALL Failed?!

Each results are 30,000 generations

(*f*= functions in network, *c*= connections)

Skull	Run 1	Run 3	Run 5	Run 7	Run 9	Run 11	Run 13	Run 15	Run 17	Run 19
										
	20f, 24c failed	20f, 29c failed	19f, 24c failed	22f, 28c failed	21f, 28c failed	16f, 22c failed	21f, 27c failed	23f, 29c failed	18f, 25c failed	25f, 28c failed

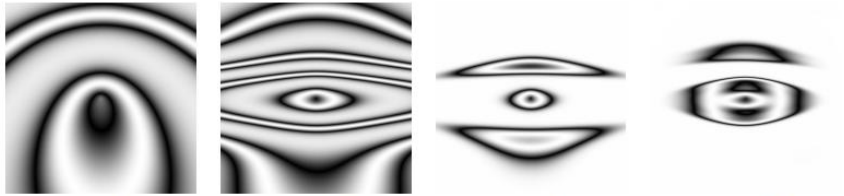
Butterfly	Run 1	Run 3	Run 5	Run 7	Run 9	Run 11	Run 13	Run 15	Run 17	Run 19
										
	22f, 27c failed	21f, 27c failed	22f, 25c failed	20f, 28c failed	18f, 23c failed	21f, 27c failed	27f, 34c failed	22f, 25c failed	24f, 29c failed	20f, 28c failed

Target

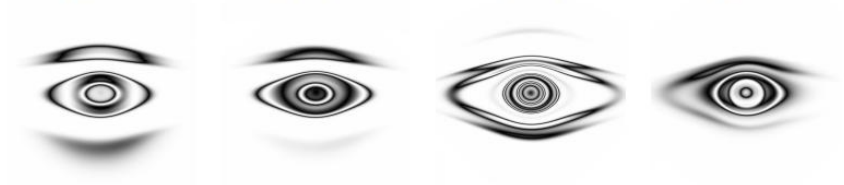
Insight 3: rethink objectives….

Eye	Run 1	Run 3	Run 5	Run 7	Run 9	Run 11	Run 13	Run 15	Run 17	Run 19
										
10f, 16c 12 gen	22f, 24c failed	18f, 18c failed	19f, 20c failed	22f, 21c failed	24f, 30c failed	18f, 24c 4,840 gen	17f, 18c failed	18f, 15c failed	16f, 21c failed	22f, 23c failed

Stepping stones of non-objective image evolution



gen 1 gen 2 gen 3 gen 5



gen 7 gen 9 gen 10 gen 12

Evolving to an objective.

gen 39 gen 60 gen 128 gen 590

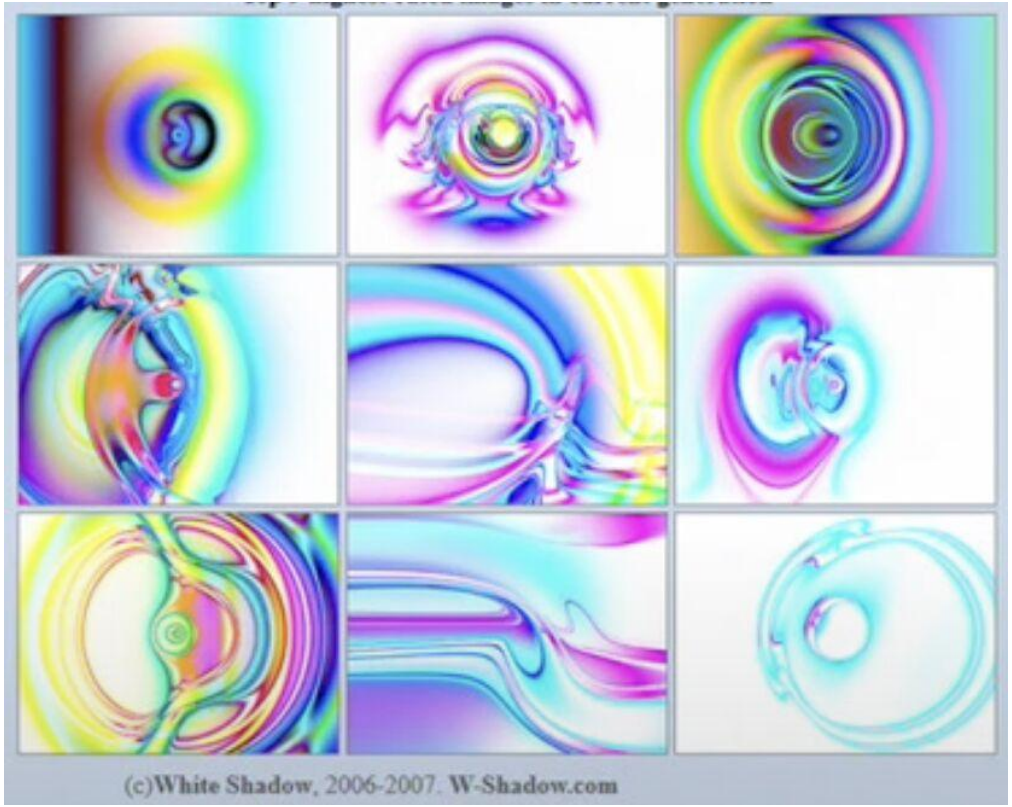
gen 2,201 gen 2,492 gen 3,429 gen 29,193

Convergent vs Divergent

Insight 4: rethink convergent consensus….

Scientific funding decisions are made this way?

Living Image Project: Based on voting (top 9 images)



PicBreeder: Based on Branching

3 main strategies from this Book

1. **No Objectives (Open-endedness)**: ‘The greatest achievements are less likely when they have objectives, so the optimal path for these great achievements is to have no objective at all as relevant stepping stones aren’t obvious and would be missed if too focused on the objective – the stepping stone doesn’t resemble the final product.’

1. **Novelty search for novel & interesting**: ‘Novelty can often act as a stepping stone detector because anything novel is a potential stepping stone to something even more novel. In other words, novelty is a rough shortcut for identifying interestingness: interesting ideas are those that open up new possibilities.’ **(a simple-to-complex information accumulat)**

1. **Be a Stepping Stone collector**: ‘Instead of judging every activity for its potential to succeed, we should judge our projects for their potential to spawn more projects. As treasure hunters, our interest is in collecting more stepping stones,not in reaching a particular destination. The more stepping stones we find, the more opportunities there are to depart to somewhere greater.’

Be a Stepping Stone collector

1. **No final objectives**: based on novelty search or interestingness
2. **Collect stepping stones**: doesn't necessarily give best solutions to a specific problem
3. **GOOD Stepping stone**: a stepping stone that can leads to more stepping stones
4. **BAD Stepping stone**: leads nowhere beyond itself, no matter how nice it may feel to stand upon it for the moment

"As treasure hunters, our interest is in collecting more stepping stones,not in reaching a particular destination. The more stepping stones we find, the more opportunities there are to depart to somewhere greater."

Strategies from ‘why greatness can’t be planned’ align with lots of previous ideas

- =Emergent Properties in Complex Systems
- Zen Philosophy (Wu Wei): the best results come when you allow things to happen naturally, without forcing them.
- Serendipity in Scientific Discovery
- Evolutionary Theory (Biological Evolution)
- Theories on The Unconscious Mind and intuitions, Eureka!

…….

Apply in
Research process

Apply in
Synthetic Biology

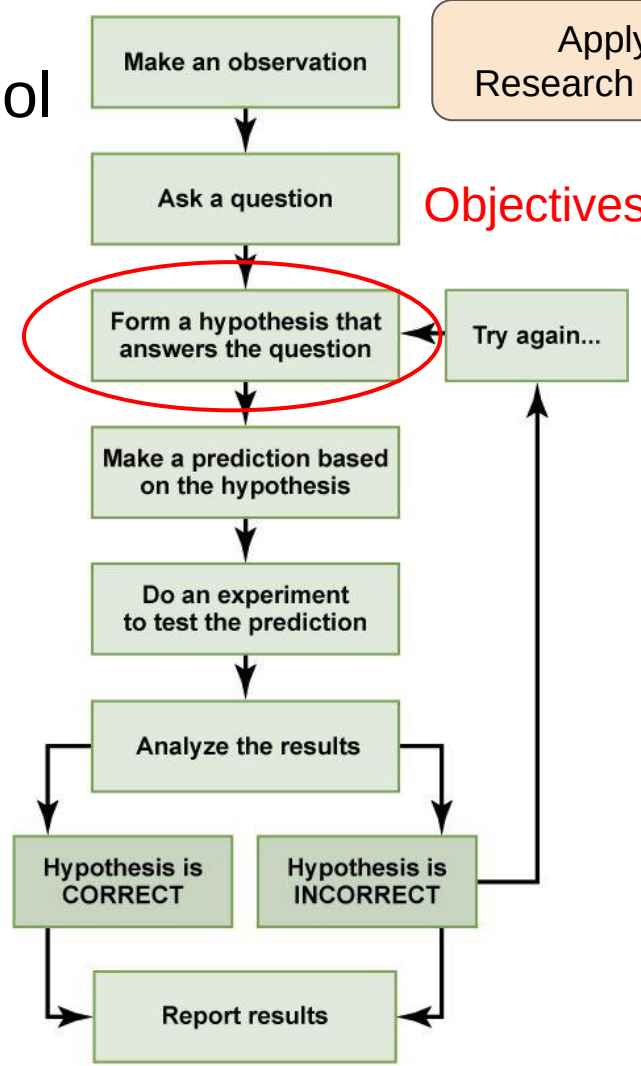
Apply in
Life, social, entr

Scientific method that's taught in school

'Finding the right direction'

Do the greatest scientific breakthroughs come from known objectives and top-down execution by following this method?

Are there any other methods?



Examples of unplanned Greatness

Science

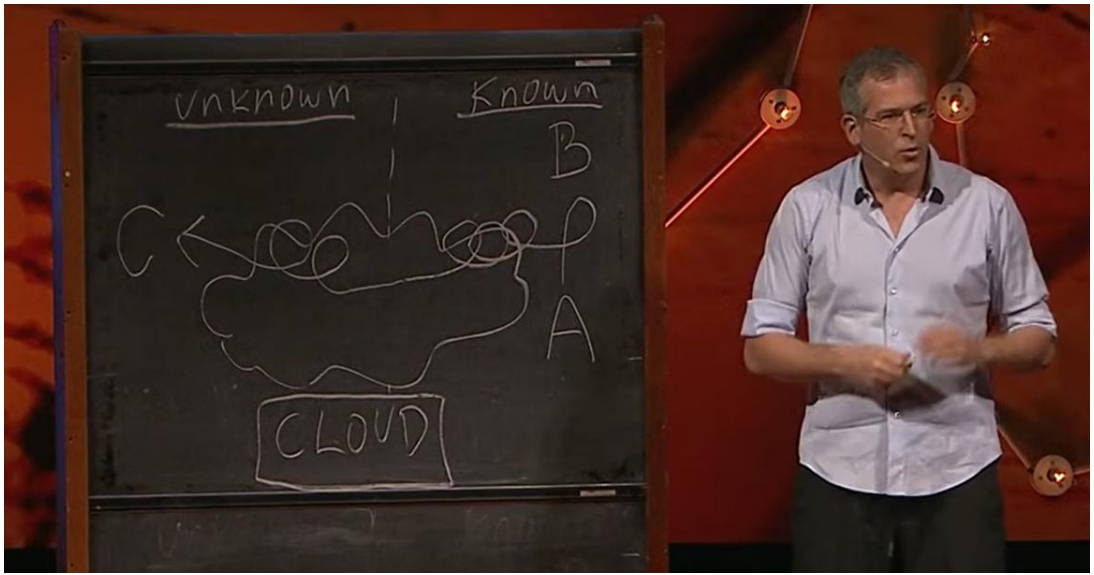
- Alexander Fleming: Penicillin
- Richard Feynman: Spinning Plates & Feynman diagrams
- CRISPR-Cas
- Percy Spencer: chocolate bar & microwave
- Vacuum Tube & computation

Entrepenurship

- Slack: Gaming company to communication platform
- Instagram: location-based check-in app to photo-sharing
- Post-it Notes: failed strong adhesive
- YouTube: dating website

In Research Proposal:
What is your objective? What is your hypothesis?

Scientific process:
Planning to get from A→B,
encounter a cloud (wasting time, feeling miserable),
drift to C instead



https://youtu.be/F1U26PLiXjM?si=Dd3TCa0dJFB3ST3X

“If A is the question,and B is the answer, then research is a direct path.

The problem is that if an experiment doesn't work, or a student gets depressed, it's perceived as something utterly wrong and causes tremendous stress.”

Forgive yourself for wasting time

"My third piece of advice is probably the hardest to take. It is to **forgive yourself for wasting time.** …..As you will never be sure which are the right problems to work on, most of the time that you spend in the laboratory or at your desk will be wasted. If you want to be creative, then you will have to get used to spending most of your time not being creative, to being becalmed on the ocean of scientific knowledge."

Four golden lessons (Steven Weinberg, 2003)

We don't know what the stepping stones are!

(YouTube) How discoveries were made?

https://youtu.be/thtKslF8zE4?si=MDbQuX1Fx--isXkC

"standing on the shoulders of giants"

Applying this strategy in Research process?

1. No Objectives (Open-endedness)
2. Novelty search for novel & interesting
3. Be a Stepping Stone collector

Correspondence | Published: 27 March 2023

Make science disruptive again

Itai Yanai & Martin J. Lercher

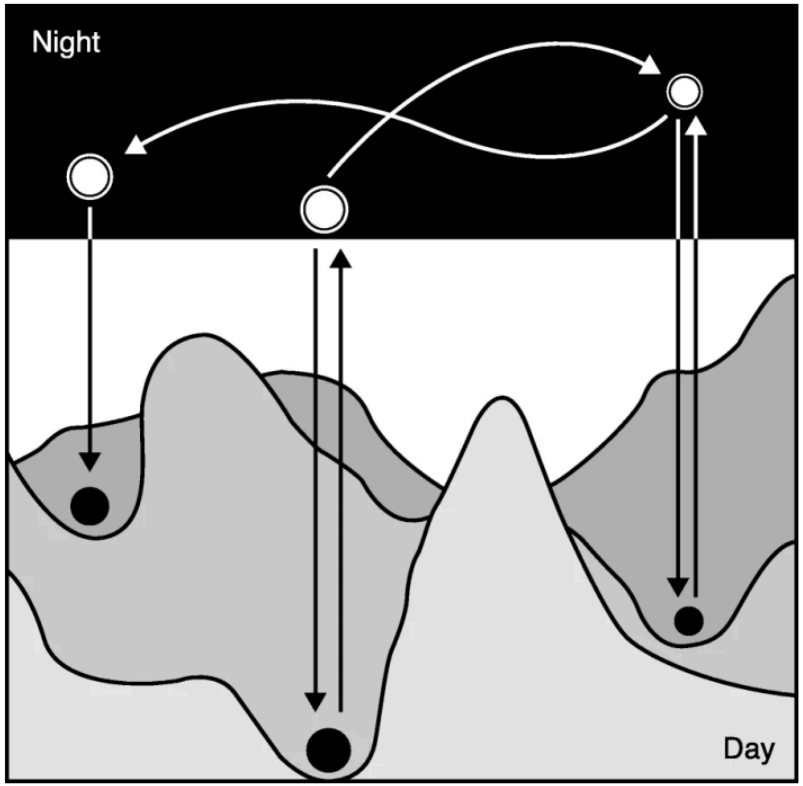
Nature Biotechnology **41**, 450–451 (2023) | Cite this article

"...the culture of science has gradually transitioned toward a more executive and results-oriented approach. In this fast-paced mode, scientists and scientists-in-training — graduate students and postdoctoral fellows — have little time for more exploratory topics, which contributes to a less creative environment for transformative science."

"...science becoming increasingly entrenched into siloed disciplines and by projects being progressively dominated by hypothesis-driven approaches, fueled by a spirit of strategic design that emphasizes predictability rather than unexpected results."

Main Question: How Do Breakthrough Innovations Occur?

Balance between ‘Day Science’ vs ‘Night Science’



Night science: creates the questions, makes connections to seemingly distant concepts and explores new directions.

Day science: the executive domain, in which we test specific hypotheses by implementing tools and designing experiments

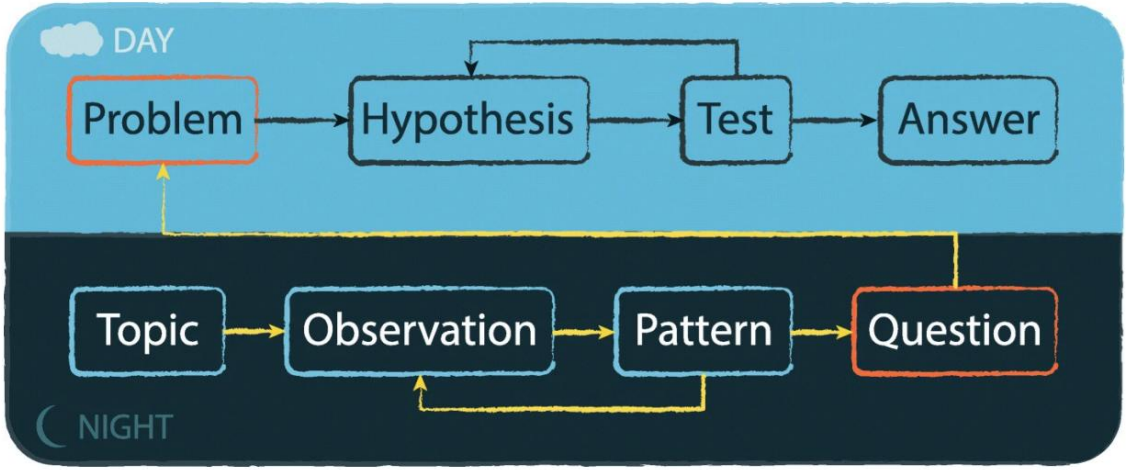
Night Science - Learning (night-science.org)
website: 8 chapters of how to apply night science

‘Hmm, this is interesting….’

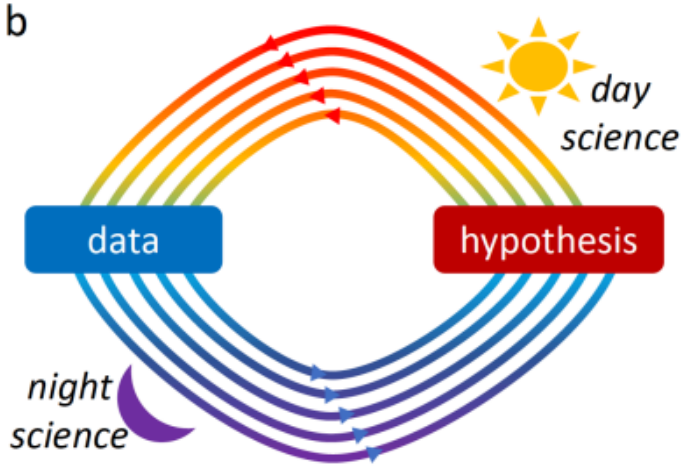
‘what if I try….’

Table 2: Distinct questions in the two languages of science

Night science questions	**Day science questions**
Why would that happen?	What is the evidence for that assertion?
What does that protein want?	Is it necessary and sufficient?
Why would the cell do something that stupid?	What is the significance (P-value)?
How does the cell know what to do?	What is the mechanism?
Why did the cell not know that it has been invaded by the virus?	Is there a negative control and a positive control?
How do these cells know to stop dividing?	Is the proposed experiment sufficiently powered?



Novelty search for novel & interesting



Hypothesis-driven vs Data-driven

make science disruptive again:
“learn how to refocus existing questions and to ask new ones: inventing the right question can advance science more than answering an existing one”

Example of ‘Night Science’: Improvisational theater in Science

How can we create new ideas?

Improvisational science

Follow the 5 easy steps!

Step 1: Find someone you can talk to.

Express ideas out loud

Creates a space for thinking broadly

Step 2: One-on-ones are the best.

t
r
vulnerable
s
t

Step 3: Think of it as an improvisation.

“Yes, and”

~~“No, but...”~~

No fixed plan or agenda

Step 4: Make them look good.

Overcoming the imposter syndrome

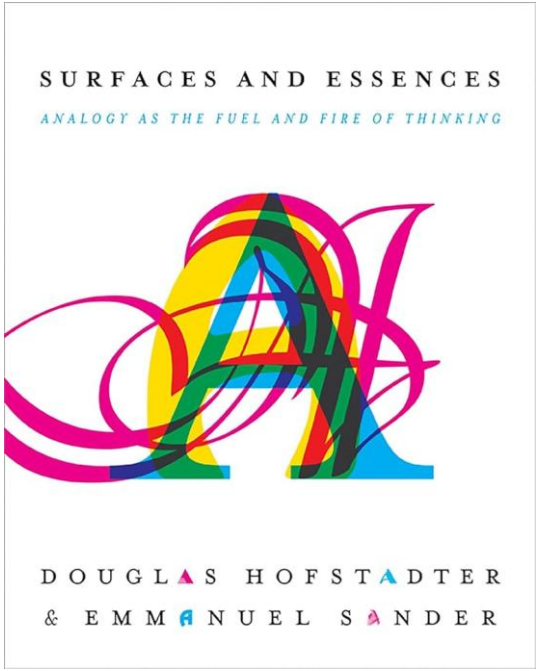
Step 5: Be the lone-genius.

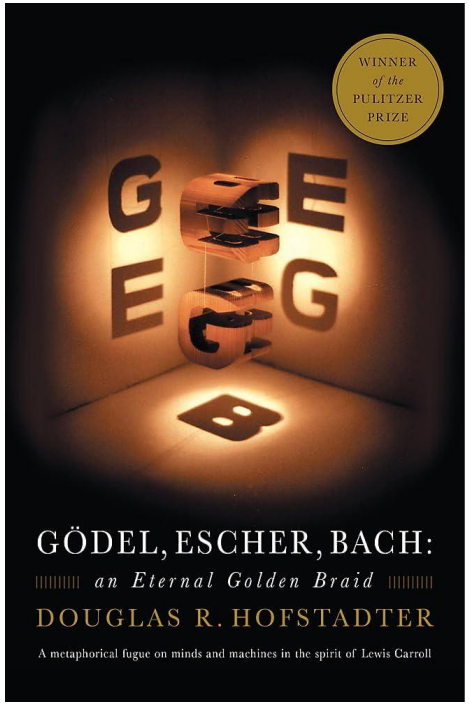
After the improvisation, take action!

Then, go back to **Step 1:**

deep discussion, more freely

Analogy & Import/Export ideas to other fields





Exporting an idea to another field

Network thinking: applying network analysis methods to internet robustness [24] (see text).

Quantum computer: bringing quantum physics to computer science [29].

CRISPR/Cas: bringing evolution and immunology to genome editing [31,32].

Douglas R. Hofstadter

Commit 20% of time to understand the bigger problem

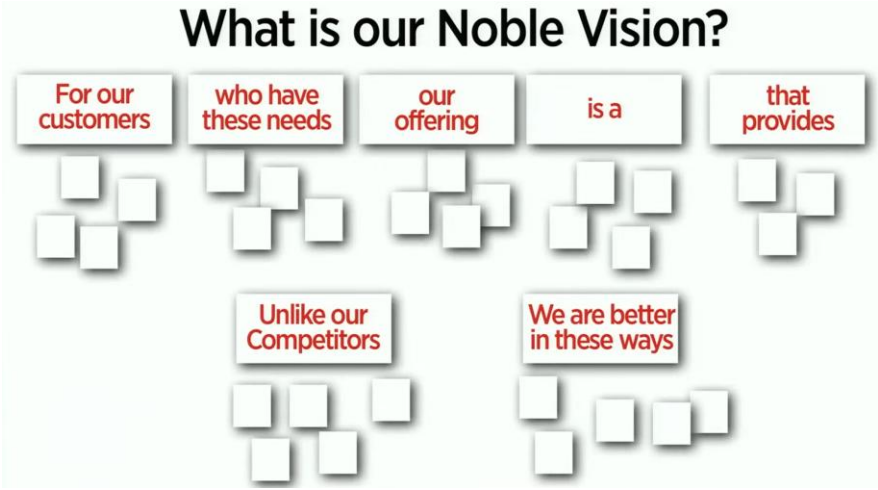
“I subscribe to Pasteur's ``Luck favors the prepared mind." I favor heavily what I did. Friday afternoons for years - great thoughts only - means that I **committed 10% of my time trying to understand the bigger problems in the field**, i.e. what was and what was not important. I found in the early days I had believed `this' and yet had spent all week marching in `that' direction. It was kind of foolish. If I really believe the action is over there, why do I march in this direction? I either had to change my goal or change what I did. So I changed something I did and I marched in the direction I thought was important. It's that easy.”
You and Your Research (Richard Hamming, 1986)

https://youtu.be/a1zDuOPkMSw?si=bceB-OW6mrXdgQPt
https://blog.samaltman.com/you-and-your-research
You and your research lecture

Brainstorm with Sticky notes

Can we do it in Journal Club/lab meetings? when discussing papers, research proposal/new projects….

1. Everyone participates, diverse background (Boss, employee…)
2. Collect many nodes (as sticky note)
3. refine multiple times (rearrange, add/remove notes)
4. Good ideas/solutions emerges



https://www.youtube.com/watch?v=_vS_b7cJn2A

Applying this strategy in Synthetic Biology?

Apply in Synthetic Biology

SCIENCE ADVANCES | REVIEW

SYSTEMS BIOLOGY

Open-endedness in synthetic biology: A route to continual innovation for biological design

Michiel Stock[1]* and Thomas E. Gorochowski[2,3]

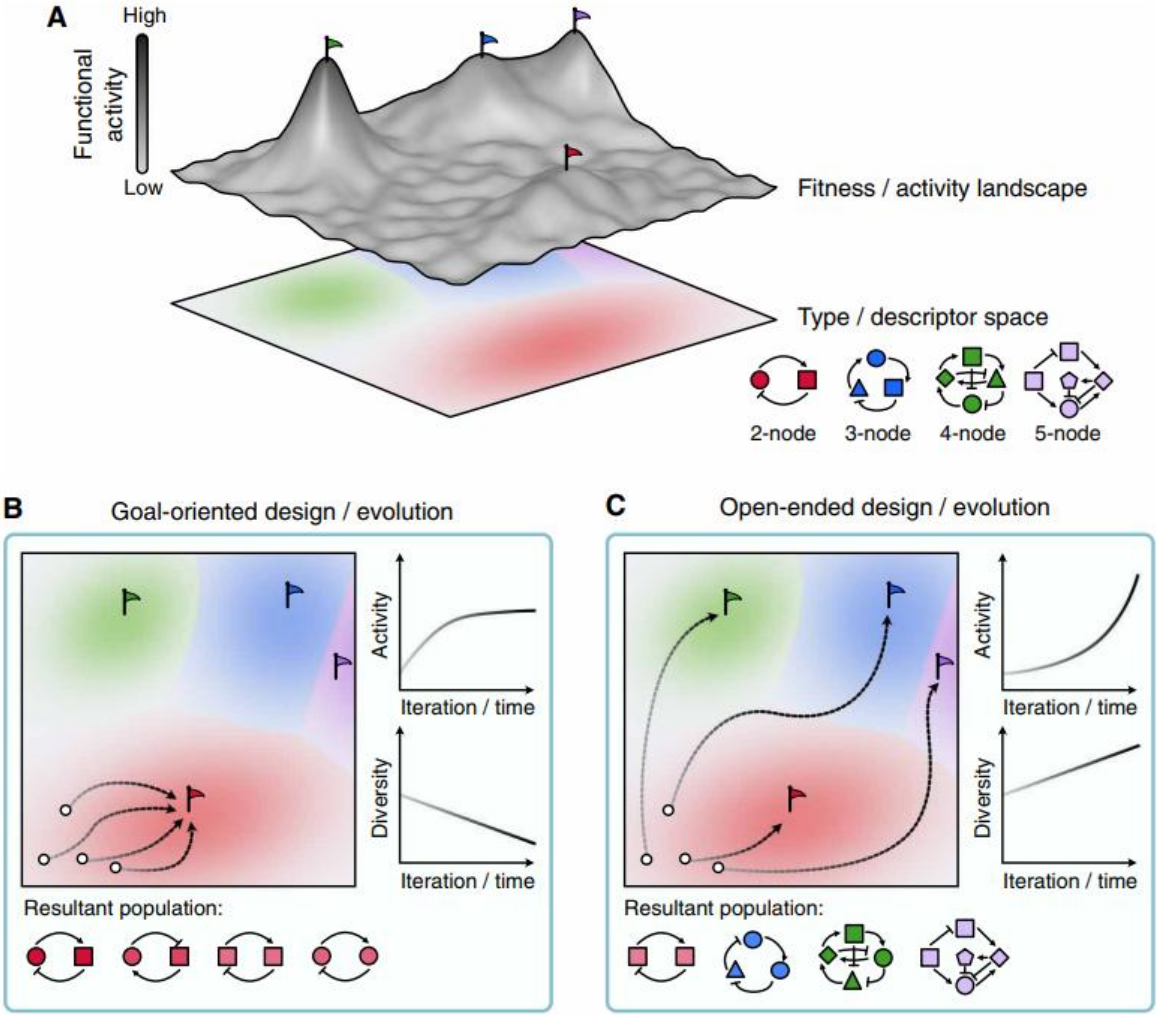
Terms (Synthetic Biology)

- **Open-ended process**: A process that continually generates novel entities or entities that can improve their functionality without bound. Open-ended processes are also sometimes characterized as having no clearly defined objective or goal
- **Open-endedness, or open-ended search**, relates to the capacity of a system to endlessly improve, produce novelty, or increase its complexity over time
- **Emergent behavior**: Behavior or properties that arise from the interactions of underlying components of the entities but which cannot be directly deduced or predicted from the characteristics of those components in isolation.
- **Creativity**: The process of creating novelty
- **Novelty:** The degree to which an entity is new or unusual, either due to novel compositions or by exhibiting new behaviors.
- **Variation:** Novelty that changes an entity by altering its internal arrangement of components.
- **Stepping stone problem:** The observation that to create an entity with a particular function, one often has to take intermediate steps that seem unrelated or counterproductive toward the end goal.
- **Optimization**: Branch of mathematics concerned with finding the best solutions to a given problem using an objective function, e.g., optimizing a metabolic pathway to maximize the yield of a desired small molecule.

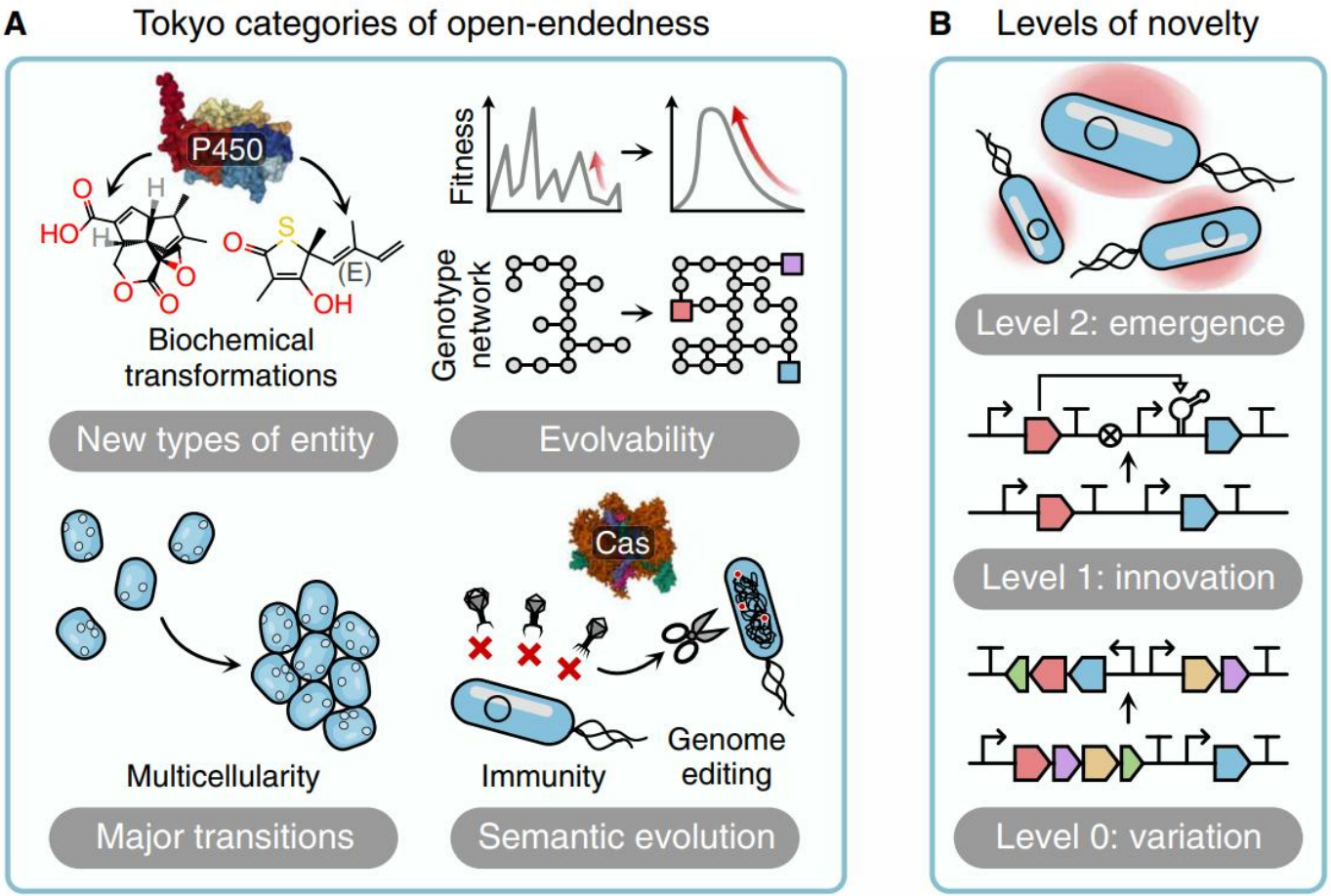
Goal-oriented versus open-ended design

Entities: proteins, genetic constructs, and engineered cell

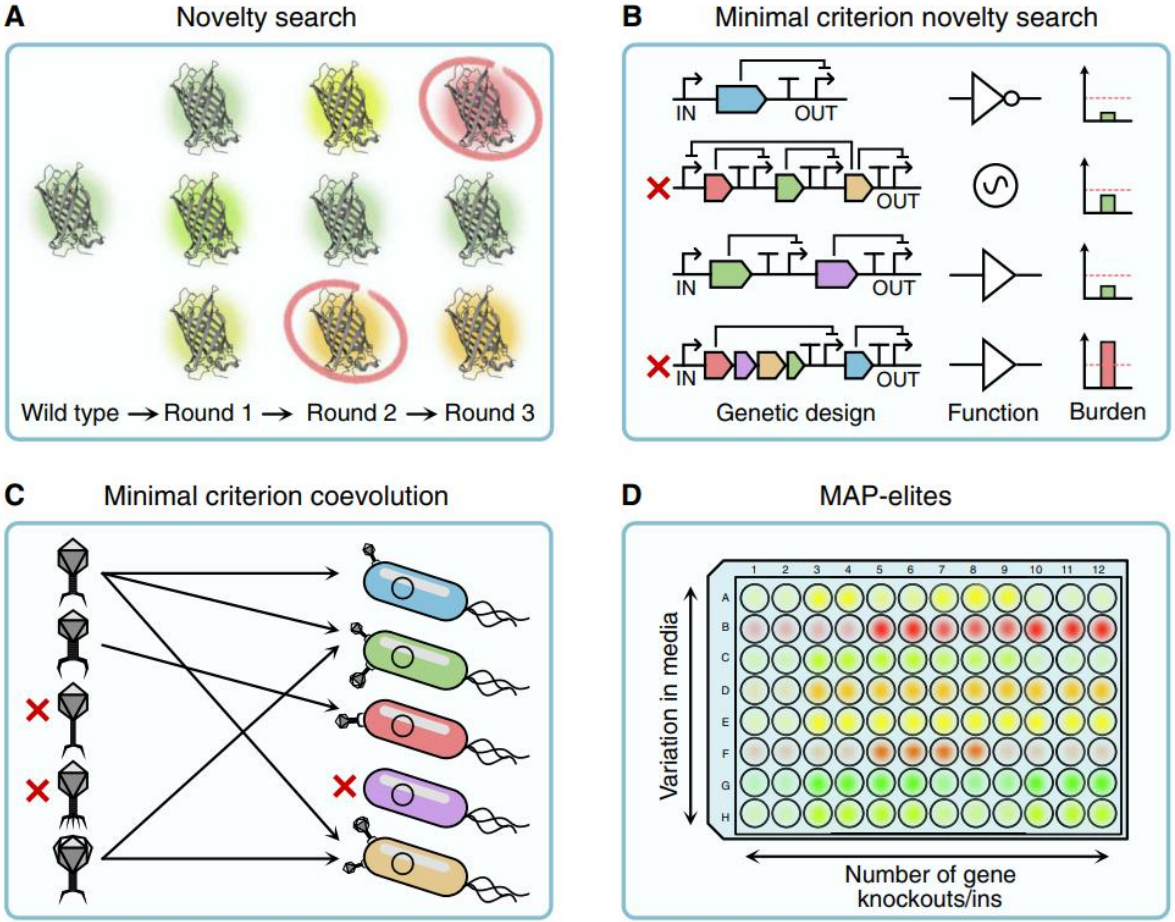
Functional activity: performance of this entities (eg. activity of proteins)



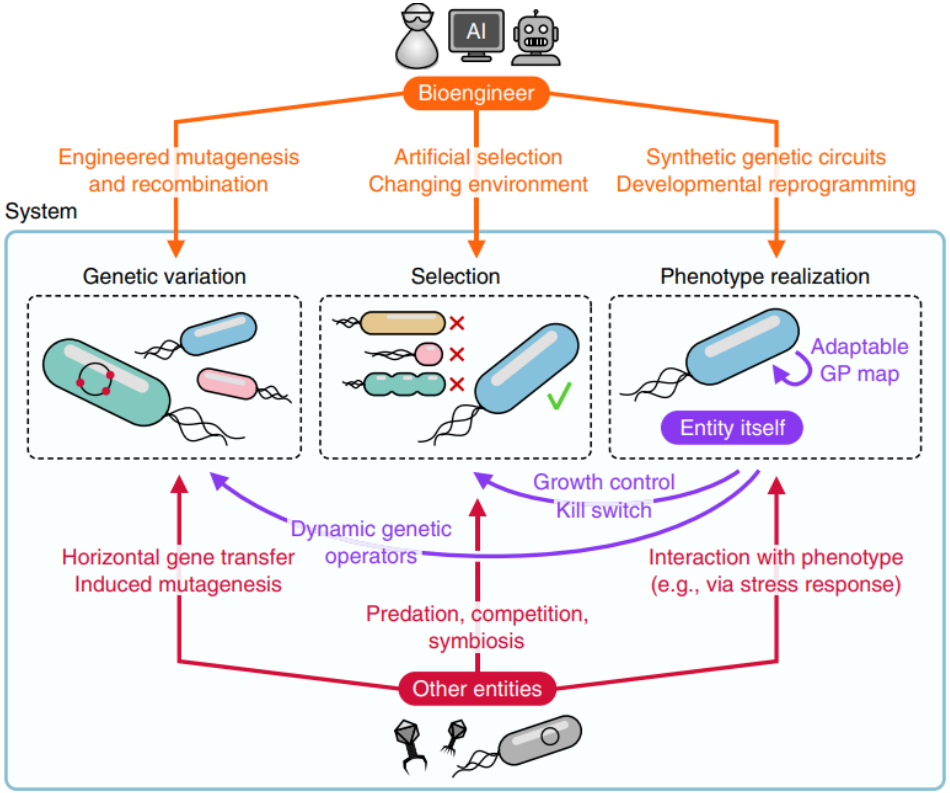
Types of Open-Endedness and Novelty in Syn Bio



Ways to create Open-Ended Design in the Lab for Syn Bio



Future: Open-ended Synthetic biology in automated lab



https://ia.samaltman.com/

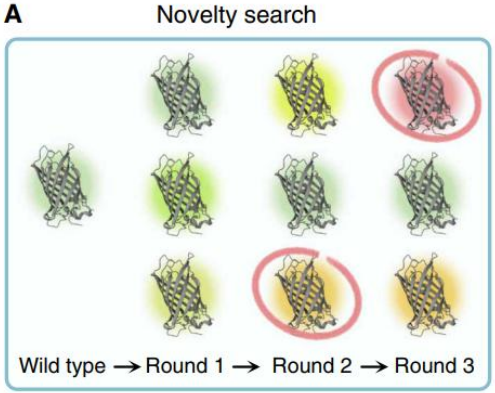
"It is possible that we will have superintelligence in a few thousand days (!)"

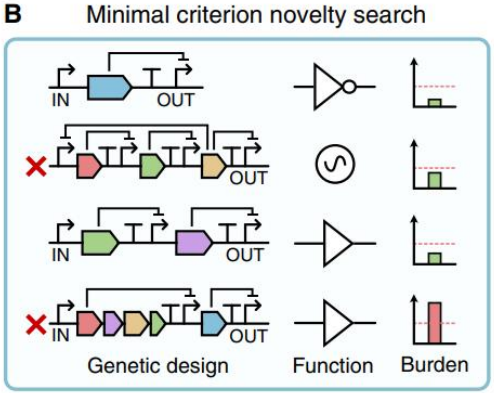
What will the future of academia be with ASI & automated lab?

Ways to Apply Open-Ended Design in the Lab for research process

*Analogy

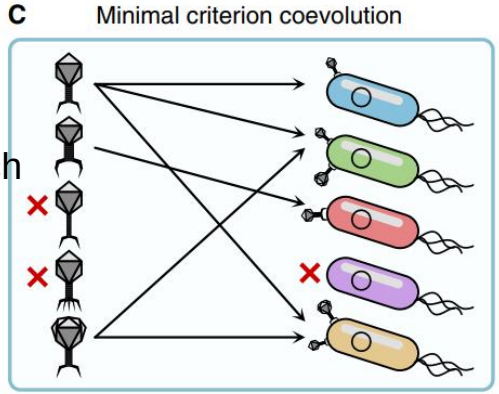
explore ideas based on novelty and uniqueness

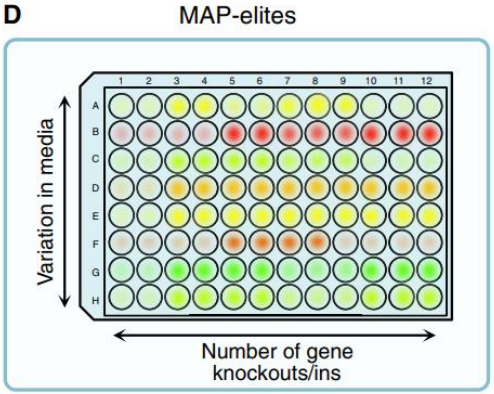




not discarding projects that show only minimal success

Encourage collaborative research across disciplines





what if the future research actually work like this? (with lower cost of execution thanks to robots/AI…)

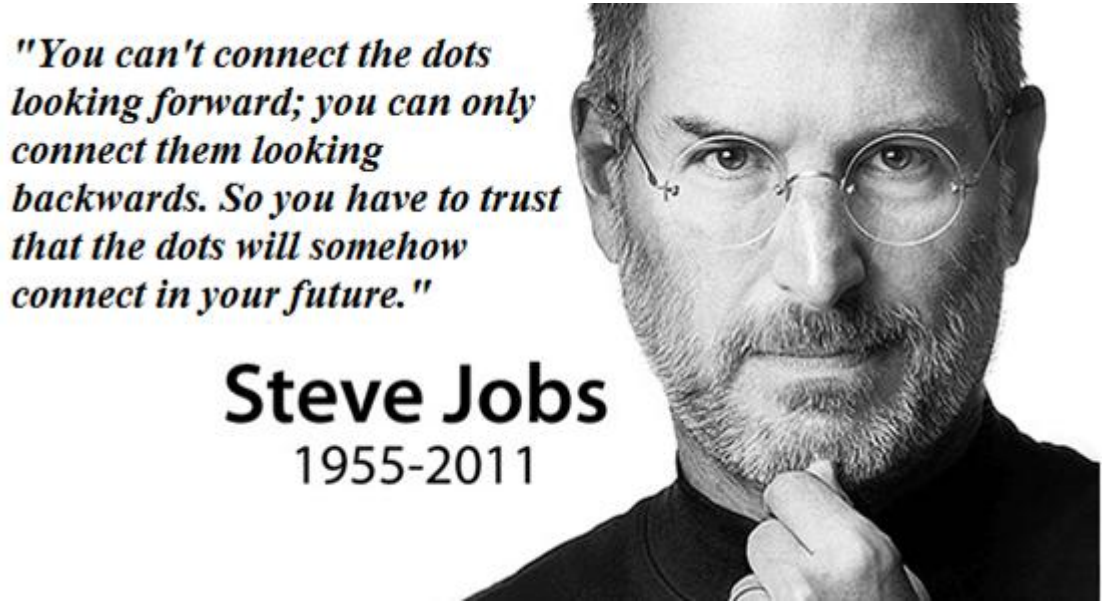
Applying this strategy in Life?

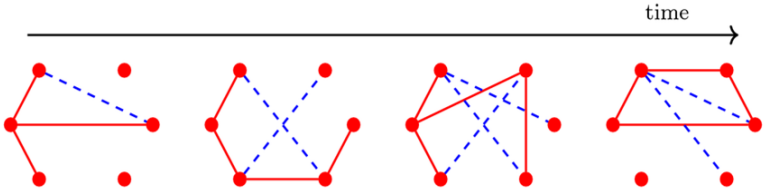
Apply in
Life, social, entr

Be a Stepping Stone collector

= Collecting the dots/nodes in the system? (eg. new people, ideas, hobbies…)

Achieve greatness in life?

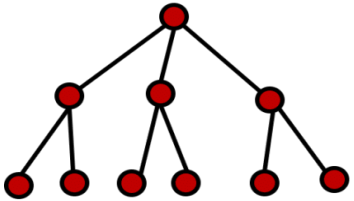




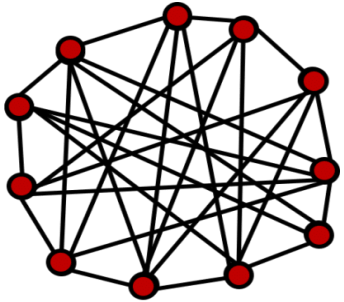
Increasing dots/node =
Increasing number of possible patterns for connecting the dots

Balance these mindsets

‘Top down’ vs ‘Bottom up’

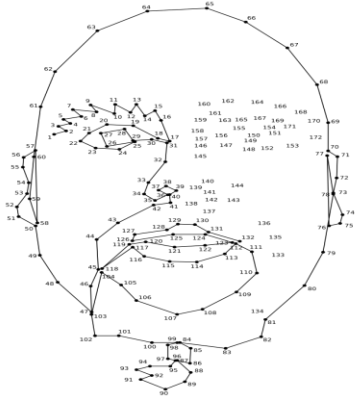


“Top-down”



“Bottom-up”

‘Finding the right direction’ vs ‘Connecting the dots’



Applying this strategy in Social?

New Social Media with Serendipity
(Made by Dr. Kenneth Stanley)

https://app.heymaven.com/discover/25380

‘Why Greatness cannot be planned’ book discussion on Maven (with Dr. Stanley’s interaction)

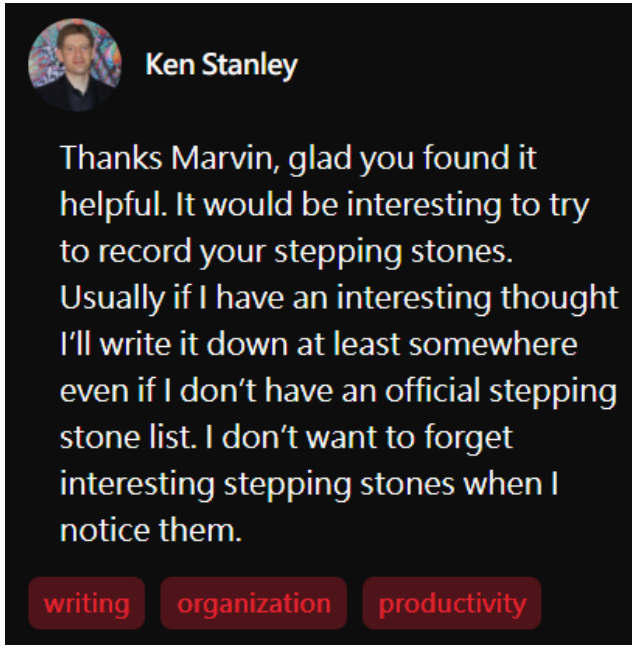
https://app.heymaven.com/discover/24925

applying novelty search in entrepenurship

https://app.heymaven.com/discover/27325

applying novelty search in synthetic biology

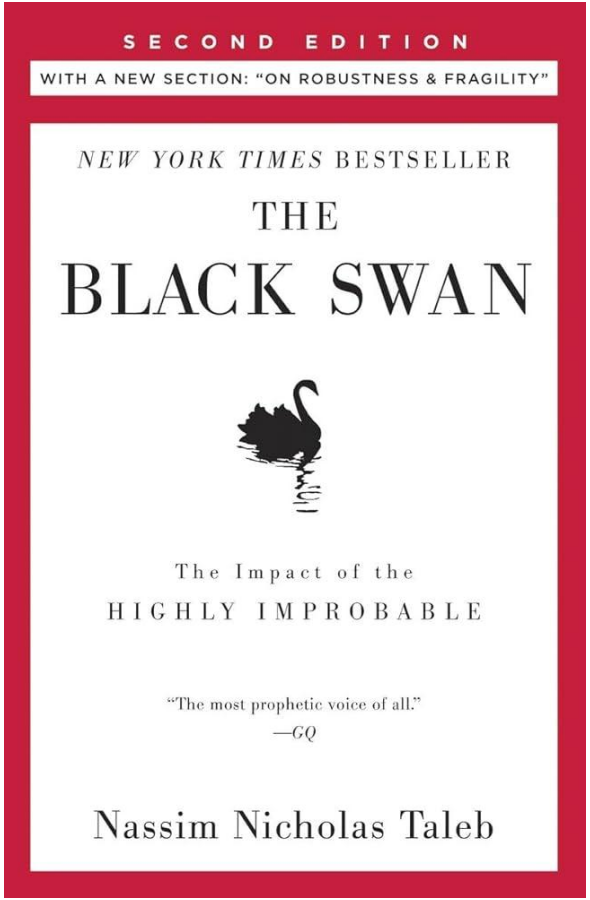
Maven



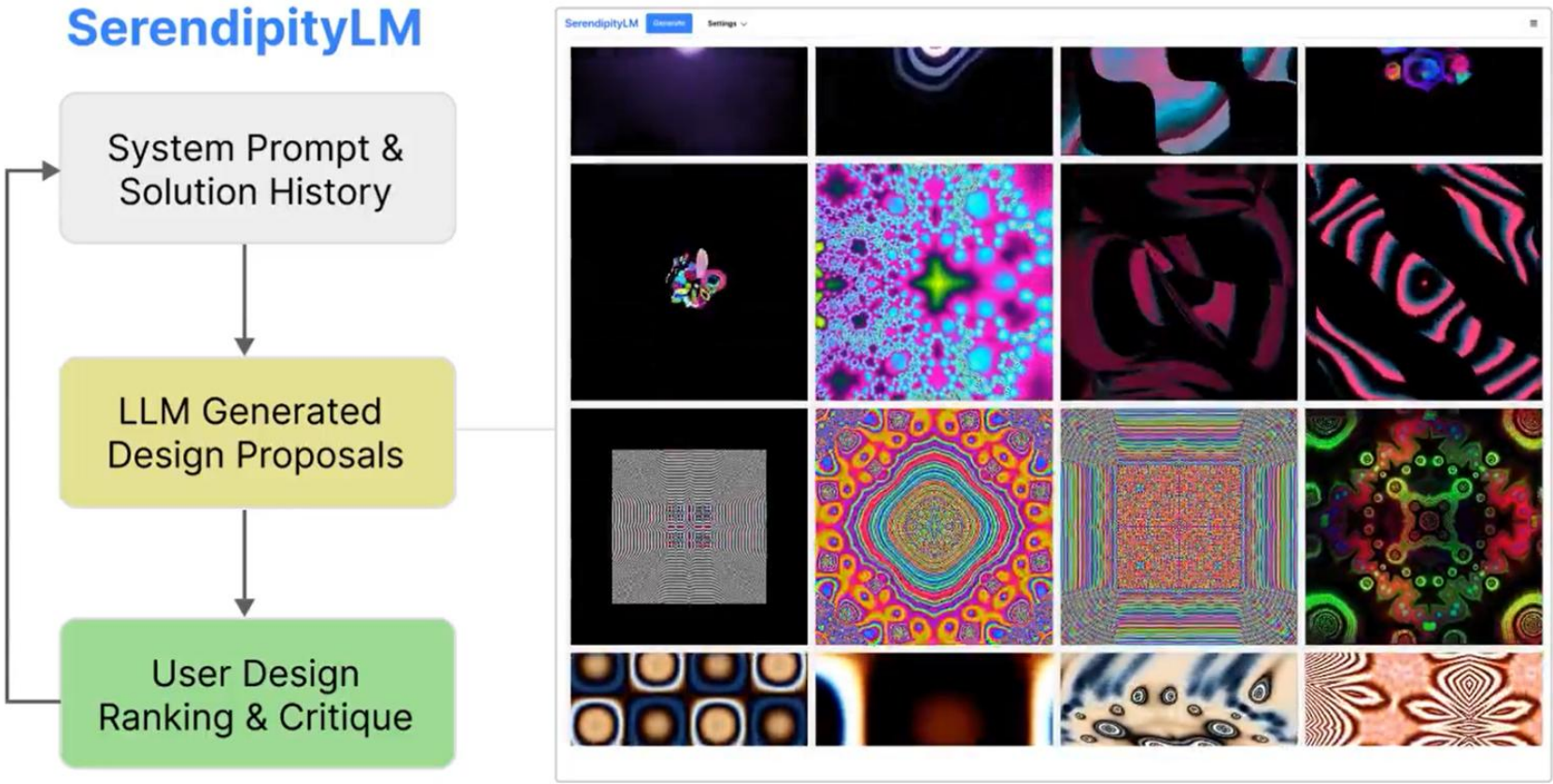
Side note: The opposite of greatness is negative black swan

we also cannot know the stepping stone to tramatic events

“Consider a turkey that is fed every day. Every single feeding will firm up the bird’s belief that it is the general rule of life to be fed every day by friendly members of the human race “looking out for its best interests,” as a politician would say. On the afternoon of the Wednesday before Thanksgiving, something unexpected will happen to the turkey. It will incur a revision of belief.”
— Nassim Nicholas Taleb, The Black Swan



Side note: 2024 version of PicBreeder: SerendipityLM



https://x.com/samim/status/1806081942787367306?s=46

Startup incubator for students

Applying this strategy in entrepenurship!

https://de.linkedin.com/company/launchrheinmain

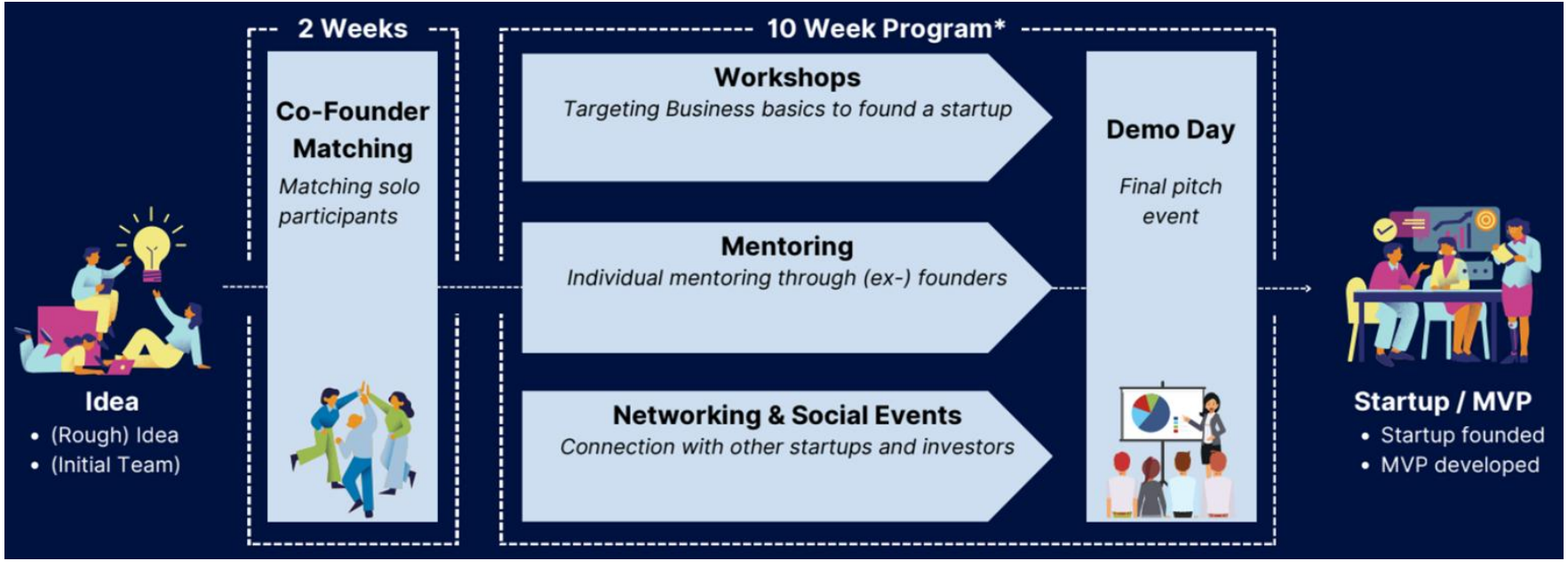
LAUNCH RHEIN-MAIN

TECHNISCHE UNIVERSITÄT DARMSTADT

JG|U

Frankfurt School of Finance & Management

German Excellence. Global Relevance.



AUFBAU DES ANGEBOTS

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Koordination | Marketing/ Öffentlichkeitsarbeit

Mentoring/ Experten

- Mentoring für Gründer:innen durch fachliche Nähe und Expertise
- bei speziellen Fragen weitere Expert:innen

Externe Dienstleister

- Ergänzung zum Mentoring, z.B. Recht, Marketing (Rahmenverträge)

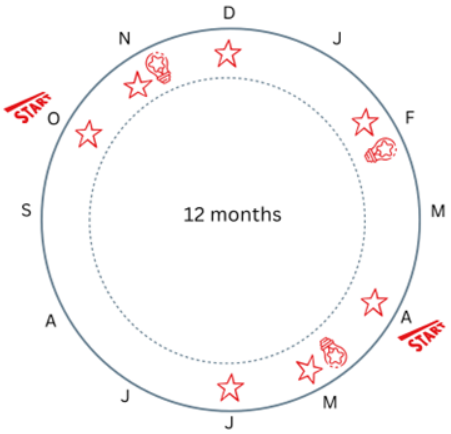
Infrastruktur

- Labor- und Büroflächen
- Zugang zu core facilities
- Vernetzung zu Kapitalgebern
- Peer Groups
- Community
- Netzwerkaufbau

Trainings

- Über gesamte Gründungskette
- Workshops/ Trainings Life Science
- Einzelberatung
- Coaching

Kadans Science Partner
Landesplattform
BioVation RLP



Networking/ Match Making/ Pitch-Events

START Entry of Inkubator for 12 months

Trainings (1 Week)

Mentoring programm

lzm. Life Science Zentrum Mainz

The End

1. **No Objectives (Open-endedness)**: ‘The greatest achievements are less likely when they have objectives, so the optimal path for these great achievements is to have no objective at all as relevant stepping stones aren’t obvious and would be missed if too focused on the objective – the stepping stone doesn’t resemble the final product.’

1. **Novelty search for novel & interesting**: ‘Novelty can often act as a stepping stone detector because anything novel is a potential stepping stone to something even more novel. In other words, novelty is a rough shortcut for identifying interestingness: interesting ideas are those that open up new possibilities.’

1. **Be a Stepping Stone collector**: ‘Instead of judging every activity for its potential to succeed, we should judge our projects for their potential to spawn more projects. As treasure hunters, our interest is in collecting more stepping stones,not in reaching a particular destination. The more stepping stones we find, the more opportunities there are to depart to somewhere greater.’

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