A Reversible Universe

(Worldview by Affordance-based Reverse Engineering of Complex Natural Systems)

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Leonardo da Vinci, 1452-1519

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"The human foot is a masterpiece of engineering… and a work of art."

[beautiful functionality]

Stephen Hawking, Physicist

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"A complete, consistent unified theory is only the first step: our goal is a complete understanding of the events around us, and of our own existence," from *A Brief History of Time*," 1988.

What is “Reverse Engineering”?

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“Some Disassembly Required”, Reverse Engineering (taking products apart to learn how they work) can be a valuable design training exercise”

- *ASEE Prism*, October 2008,

Consider a classic example

Greek Island of Antikythera

Example: Antikythera Mechanism

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- Discovered 1901
- Lost ~100 BC
- Complex gearing
- 100 years of RE
- Predicts celestial positions
- First analog computer
- 1000 years early!

Antikythera Mechanism: Main Fragments

Antikythera Mechanism: Schematic & Model

Information about the Maker

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"…the letters were so precise

they must have been engraved not by a labourer

but by a highly trained craftsman."

p.55, *Decoding the Heavens*

Information about Origin & Destination

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"Scrutinizing the details of the gearwheels and inscriptions, however, wasn't the only way to investigate the mechanism…

archaeologists also studied the rest of the salvaged cargo [& culture]. Their discoveries help to paint a vivid picture of when the ship sailed,

where her load was being taken and the sort of world from which she came.

From there, we can guess at the origins of the Antikythera Mechanism itself, and how it ended up on its final journey." p.61, *Decoding the Heavens*

Reverse Engineering of Natural Systems?

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National Academy of Engineering – One of 14 Grand Challenges for the 21st Century:

Reverse Engineering the Human Brain

Nanoscale Resolution MRI

Reverse Systems Engineering the Cell

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Dr. Gaudenz Danuser, Scripps Research Inst.

"Today, he does what he calls *reverse systems engineering* of dynamic cellular processes -

Analyzing how cells accomplish complicated feats like movement by applying a large framework of statistical processing to measurements of moving cells." – "Mechanical Biology, Research on the Leading Edge"

Engineering: Key to Unlocking Biology?

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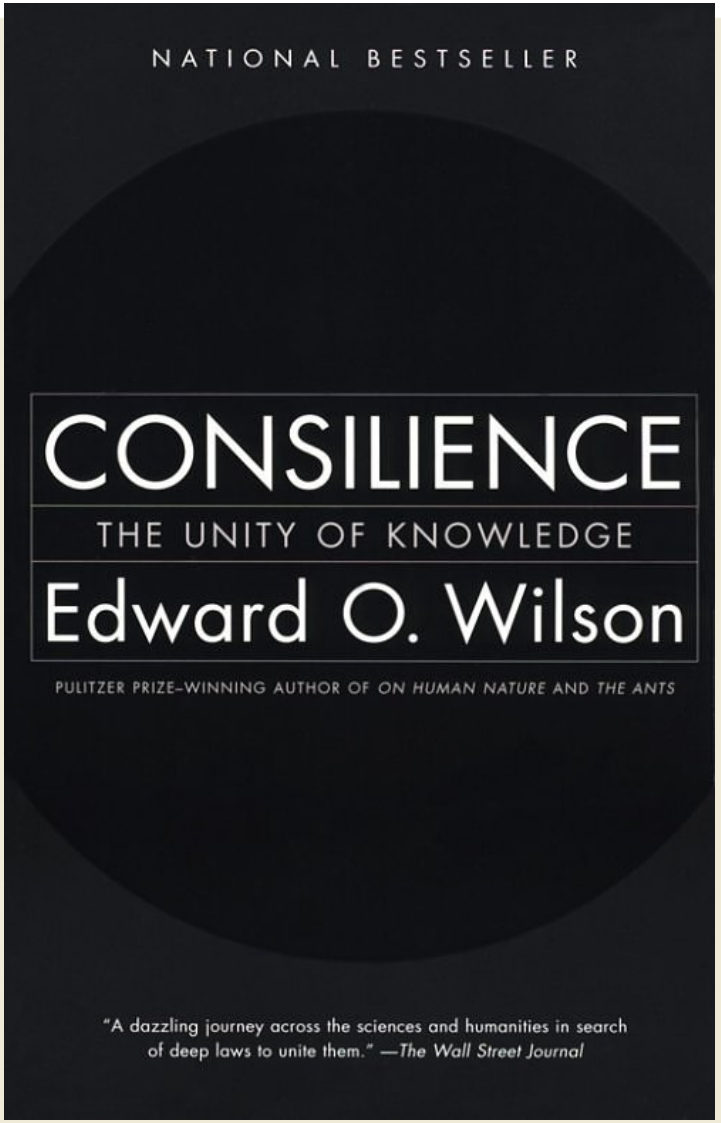
"The surest way to grasp complexity in the brain, as in any other biological system, is to think of it as an engineering problem…

Researchers in biomechanics have discovered time and again that organic structures evolved by natural selection conform to high levels of efficiency when judged by engineering criteria." (p. 112)



"Biology's Next Breakthroughs" Kate Bourzac (Systems Biology) Technology Review, MIT, 5/2/08

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Bacterial Flagellum is example of "Design Isomorph" (man-made device that was later discovered in nature!... Just a co-incidence?)

"Traditional biology tends to study one gene or protein or process at a time. *Systems biology* takes a clue from *engineering* and treats organisms as complex systems."

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Jan 2008 IEEE Transactions, Joint Issue on Automatic Controls and Circuits & Systems

Special Issue on Systems Biology

"Systems biology is the quantitative analysis of networks of dynamically interacting biological components, with the goal of *reverse engineering* these networks to understand how they robustly achieve biological function." - editorial

The Design Matrix, a Consilience of Clues
by Mike Gene, 2007

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A Convergence Between Biology and Engineering

i.e. Using synthetic biology to produce Biofuels

"Without [using] *mechanical design functions*, molecular biologists would have tremendous difficulty understanding what is happening inside the cell, planning experiments, and interpreting…their experiments." – p. 57

Treating Biological Systems as "Devices"

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Eisenberg, R., "Look at Biological Systems through an Engineer's Eyes", *Nature*, 447, p. 376, May 24, 2007.

"But it seems clear, at least to a physiologist, that productive research is catalyzed by assuming that most biological systems are devices. Thinking today of your biological preparation as a device tells you what experiments to do tomorrow."

Biomimetics: Mimicking Natural Systems

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"Multi-functioning and Multi-optimization in Feathers"

S.C. Burgess, Mechanical Engineering Dept., U. of Bristol, UK, *International Journal of Design & Nature*, 2007

"The design of bird feathers demonstrates that multi-functioning and multi-optimization can produce large benefits in performance…Nature can be a rich source of ideas and inspiration…to achieve multi-functioning in engineering."

Systems Engineering on the "Bio-Nano Frontier"

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"This frontier lies at the convergence of biotechnology, nanotechnology, and information technology… across traditional disciplinary boundaries."

"On Reverse Engineering" by M.G. Rekoff

IEEE Transactions on Systems, Man and Cybernetics, 15(2), 1985

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- **Reverse Engineering – "the act of creating a set of specifications for a piece of hardware by someone other than the original designers, primarily based on analyzing and dimensioning a specimen or collection of specimens"**
- **Very similar to detective work, CSI, or military intelligence operations**

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In a nutshell, reverse engineering is…

“the decomposition of existing structural hierarchy in developing functional specifications until the mechanism of operation is completely understood”

Step by Step Procedure for Reverse Engineering

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1. "System-engineer" to establish hypotheses based on the information presently at hand and to identify the measurement/test needs
2. Disassemble to the extent required to verify or modify the hypotheses and to perform supporting tests
3. Further "system-engineer" on the basis of all the information in hand, form new hypotheses, and prepare for additional measurement and testing
4. Further disassembly, measurement, and test to validate hypotheses and uncover new information (continue as needed)

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For any particular item within the hierarchy…

1. Assimilate existing data
2. Identify interacting elements
3. Disassemble
4. Analyze, test and measure
5. Record findings

Schematic of E. Coli Heat Shock Mechanism

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Claire Tomlin (engineer) & Jeff Axelrod (biologist) at Stanford U.,

"Understanding biology by reverse engineering the control"

Simulation shows robustness and efficiency afforded by info pathways

"what a well-trained control engineer would design"

Product Design by Otto and Wood

E. Coli heat shock study is example of the "subtract and operate" technique for reverse engineering

"Reverse Engineering & Design Recovery: A Taxonomy" by Chikofsky & Cross, *IEEE Software*, January, 1990

- **Design Recovery – "A subset of reverse engineering in which domain knowledge, external information, and deduction or fuzzy reasoning are added to the observations of the subject system…**

  to identify meaningful *higher level abstractions* beyond those obtained directly by examining the system itself"
- **Simply, what the system was engineered to do, *and why*!**

What was the design engineer thinking?

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“Design recovery must reproduce all the information required for a person to fully understand what a system does, how it does it, why it does it, and so forth.”

The problem is handling the complexity!

"The complexities of systems thinking and user interactions require engineers to move beyond simply designing [reversing] for product function." - Maier

"Rethinking Design Theory" by J. Maier,

***Mechanical Engineering*, September, 2008**

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J. Maier proposes the concept of affordance (what a system provides to an end user, or to another system)…
as an underlying and unifying principle in the science of design, and hence also reverse engineering.

http://www.the-design-works.com/

Affordances are clues, & signs of purpose!

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“Affordances provide strong clues to the operations of things.”
– Donald Norman

The Designer-Artifact-User System

"On the Complexity of the Designer-Artifact-User System" Maier & Fadel

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Affordances capture important interactions within the Designer-artifact-user system (big picture).

Designer-Artifact-User-Investigator

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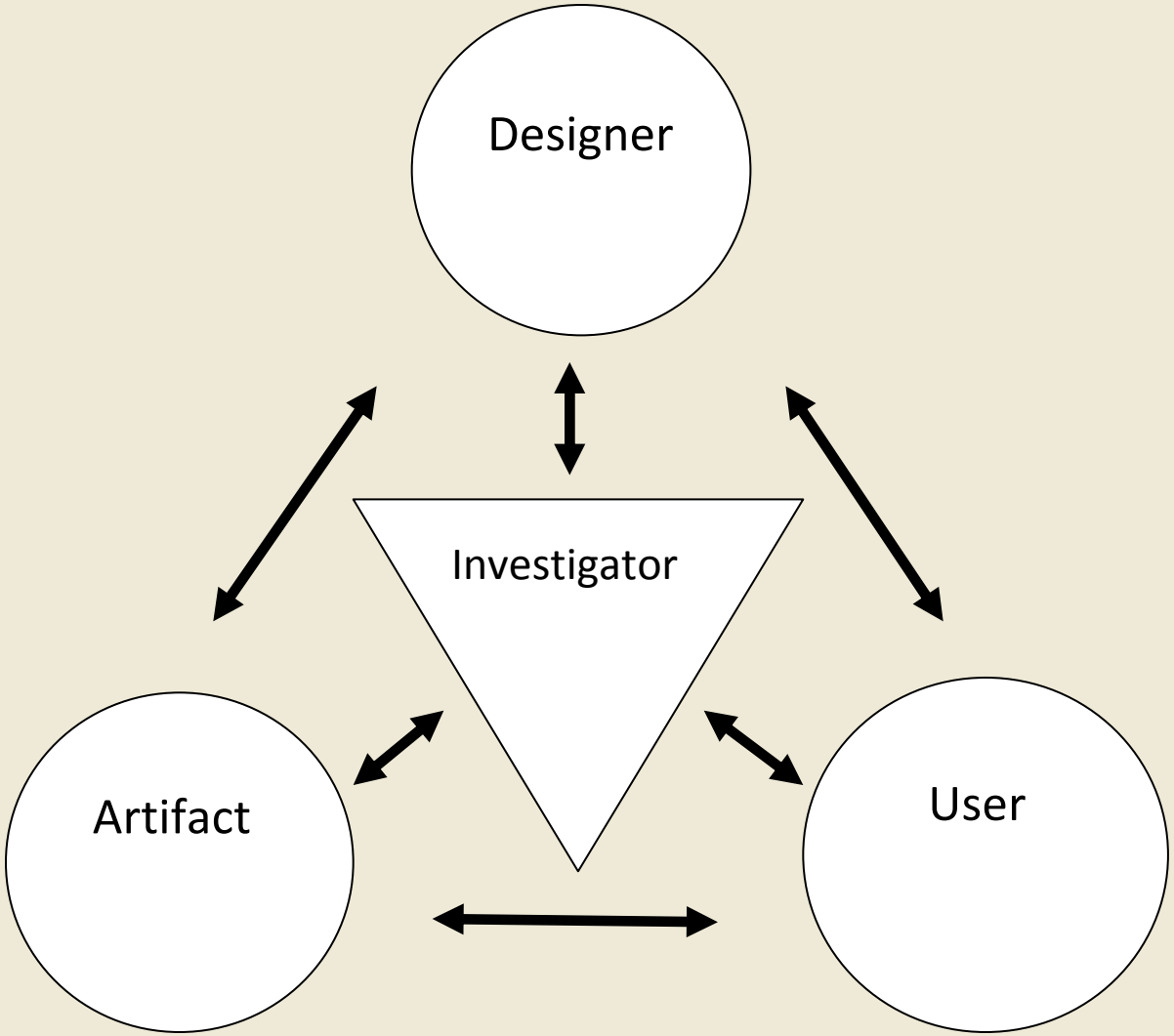
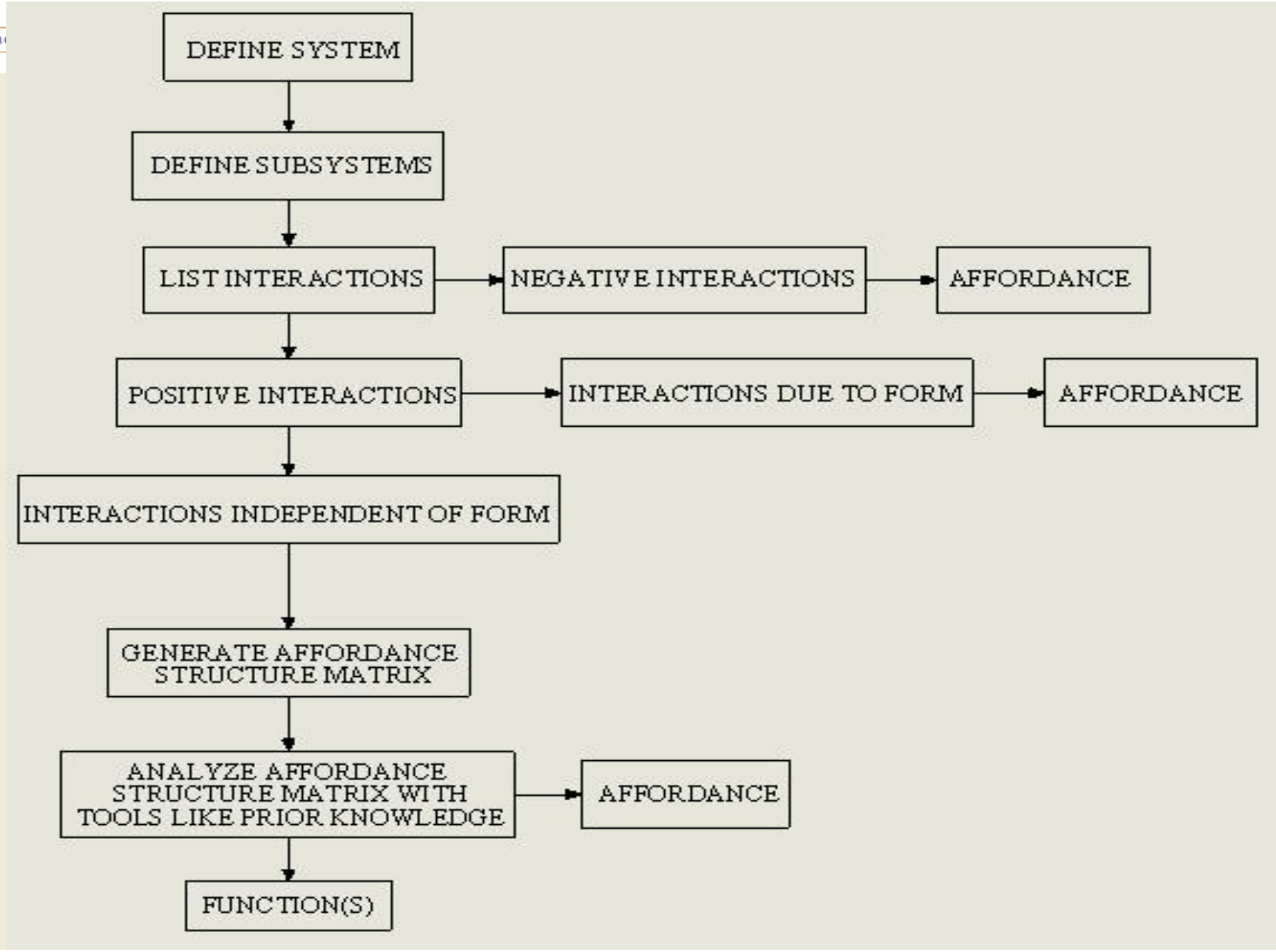


Affordances are also key to capturing important interactions during reverse engineering studies.

Affordances can be +/- and have “quality”

Affordance-based Reverse Engineering



ORU Affordance Structure Matrix (ASM)

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“The development of a comprehensive ASM demonstrates that a system has been effectively reverse engineered in the sense that its operation is now well understood.”

Affordances of the Mind-Body System

The Existence of God, 2nd Edition, Richard Swinburne, 2004

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1. Sense organs with great capacity to receive information
2. An information processor to turn sense organs into brain states (giving rise to beliefs)
3. A memory bank to file states correlated with past experiences (needed to reason)
4. Brain states that give rise to desires (both good and evil)
5. Brain states caused by various purposes that we have
6. A processor to turn these states into body movements
7. Brain states that are not fully determined by other physical states (allowing free choice)

Allow us to affect world, others, & ourselves for good or ill.

That we have these affordances tells of meaning & purpose.

"Affordances Are Signs" John Pickering, *TripleC* 5(2), 2007

Influence on the Investigator?

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"I cannot see as plainly as others do, and as I should wish to do, evidence of design and beneficence on all sides of us. There seems to me too much misery in the world…

On the other hand, I cannot anyhow be contented to view this wonderful universe, and especially the nature of man, and to conclude that everything is the result of brute force.

I am inclined to look at everything as resulting from designed laws, with the details, whether good or bad, left to the working out of what we may call chance. Not that this notion at all satisfies me.

I feel most deeply that the whole subject is too profound for the human mind. A dog might as well speculate on the mind of Newton. Let each man hope and believe what he can."

- Charles Darwin

ORU Science & Engineering Influence Worldview

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Natural systems are extremely well-engineered for life.

In addition, natural systems are readily and profitably reverse-engineered by human beings… Suggesting the hypothesis that such systems were engineered in the first place!

Integrated affordances point to an engineering influence, or a *calculating intentionality*, throughout the realm of nature.

Knowledge: Our Chief Purpose?

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"The chief purpose of life, for any one of us, is to *increase according to our capacity, our knowledge of God*, by all the means we have, and to be moved by it to praise and thanks."

One good way to get to know a *"distant"* artist, inventor, or engineer than to study his/her great works!

J.R.R. Tolkien

Leonardo da Vinci, 1452-1519

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“I have offended God and mankind…

because my work didn’t reach the quality it should have.”