Irreducible Complexity

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April 7, 2015

A term coined by Michael Behe:

> *Irreducible complexity is just a fancy phrase I use to mean a single system which is composed of several interacting parts, and where the removal of any one of the parts causes the system to cease functioning. (Behe, 1996)*

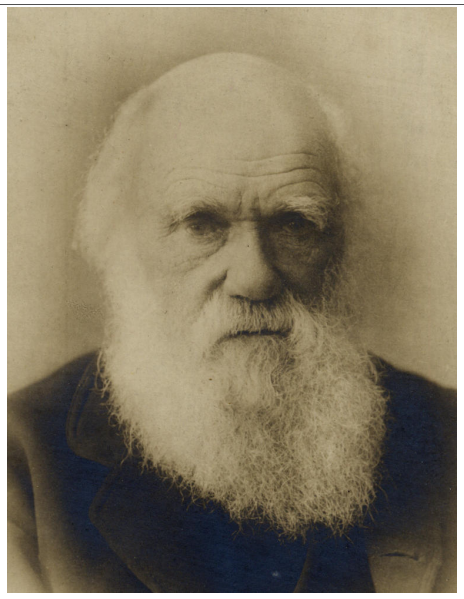
Now widely used to argue that evolution cannot account for complex adaptations.

Outline

- History of irreducible complexity
- Bacterial flagellum
- Blood clotting cascade

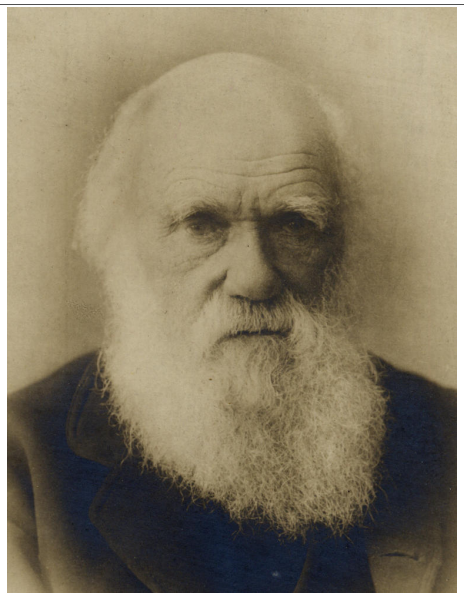
Not a new idea

"The entirety of an organic being forms a coordinated whole, a unique and closed system, in which the parts mutually correspond and work together in the same specific action through a reciprocal relationship. None of these parts can change without the others changing as well."
(Cuvier, 1831, p 59)



Charles Darwin

"If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down." (Darwin, 1859)



Charles Darwin

"We should be extremely cautious in concluding that an organ could not have been formed by transitional gradations of some kind." (Darwin, 1859)

Went on to explain, with examples, how selection can construct organs with irreducible complexity.

Charles Pritchard
(1866)

First to argue that vertebrate eye could not plausibly evolve.

Change in any part requires simultaneous delicate adjustments in all other parts.

Not plausible that this could happen by natural selection.

We now know that Pritchard was wrong

The eye evolved gradually, by individually-adaptive steps.

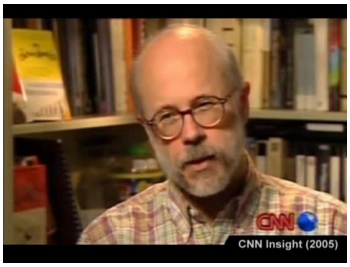
Selection can construct irreducible complexity.

Pritchard's argument was just a failure of imagination.

Michael Behe

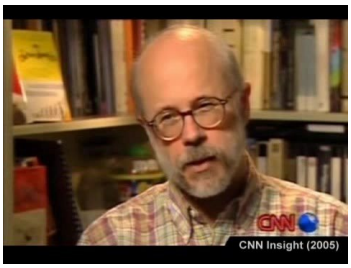
Coined term "irreducible complexity."

Knows that irreducible complexity can evolve:



Demonstration that a system is irreducibly complex is not a proof that there is absolutely no gradual route to its production. Although an irreducibly complex system can't be produced directly, one can't definitively rule out the possibility of an indirect, circuitous route. (Behe, 1996)

An underlying assumption



"as the complexity of an interacting system increases, the likelihood of such an indirect route drops precipitously." (Behe, 1996)

Sounds plausible, but is it true?

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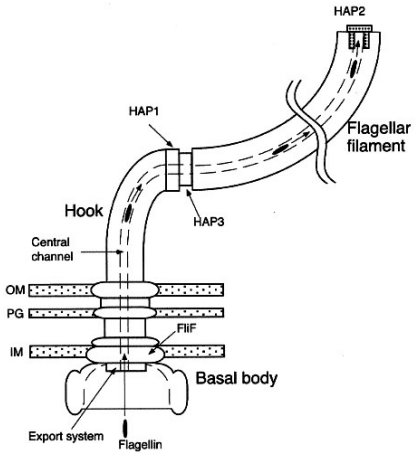
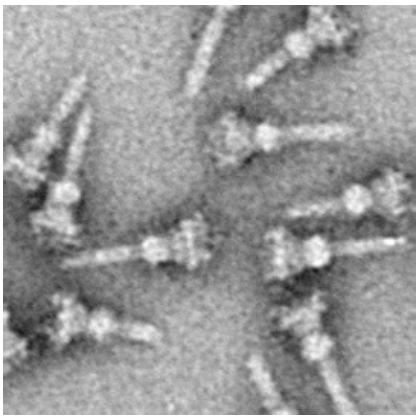


(Yonekura et al 2000)

Bacterial flagellum

About 30 proteins

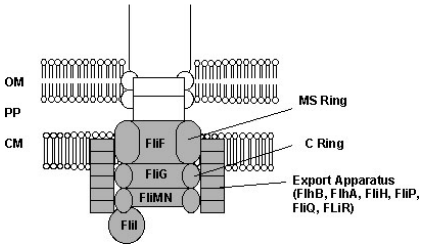
"Because the bacterial flagellum is necessarily composed of at least three parts—a paddle, a rotor, and a motor—it is irreducibly complex. Gradual evolution of the flagellum. . . faces mammoth hurdles"
(Behe, DBB, p. 72)



Type-III Secretory System

Cellular hypodermic syringe

Used by some bacteria (including bubonic plague) to inject toxins into cells of host.



(Hueck 1998)

Homologies with type-III secretory system

Gray shows proteins homologous between bacterial flagellum and type-III secretory system.

A subset of flagellar proteins has a function unlike that of flagellum.

Flagellum *not* irreducibly complex.

(Miller 2004)

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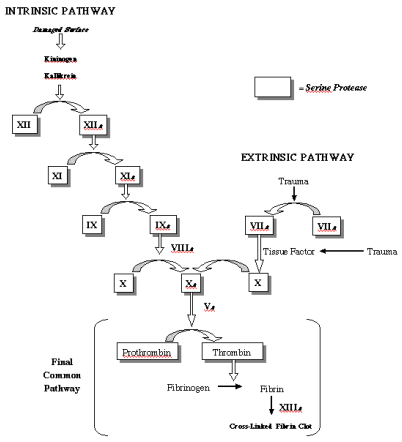
How blood doesn't clot

- *Fibrinogen*, a protein in blood, has a sticky portion.
- Sticky piece usually covered by molecules with negative charge.
- These repel, so fibrinogen molecules don't stick together.
- Blood flows freely through circulatory system.

How blood clots

1. An enzyme, *thrombin*, cuts the covers off of fibrinogen molecules, which then stick together as clots.
2. Thrombin is usually inactive—activation requires another enzyme, called *Factor X*.
3. Factor X works only if activated either by *Factor VII* or *Factor IX*.
4. And so on, as shown in next slide.



(Miller & Levine)

Blood clotting pathway

At each step, number of molecules is multiplied by 20× or 30×. Total amplification exceeds a million fold.

Can such a system evolve?

"The blood clotting system fits the definition of irreducible complexity. That is, it is a single system composed of several interacting parts that contribute to the basic function, and where the removal of any one of the parts causes the system to cease functioning." (Behe, 1996, *Darwin's Black Box*, p. 86)

Is the clotting system irreducibly complex?

- *Hemophilia* A: mutational damage to clotting factor VIII.
- *Hemophilia* B: mutational damage to clotting factor IX.
- Mild cases result from mutations that reduce activity of protein.
- Life expectancy: 11 y for severe untreated cases.

- Animals with low blood pressure don't need clotting systems.
- Many insects don't have them.

600 my ago, a small ancestral pre-vertebrate with a low-pressure circulatory system

- Would have had white blood cells, which are sticky and tend to plug leaks.
- For internal signalling, each cell would have had *proteases*—enzymes that cut proteins.
- When a cell breaks, proteases are dumped into circulation and begin chopping up protein.
- Some broken proteins are less sticky, some are more sticky.
- The sticky ones would clump and plug leaks.

All this reduces bleeding in animals without clotting systems.

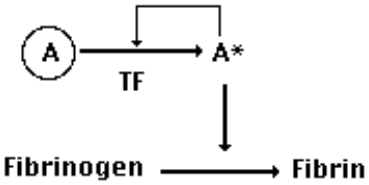
A small improvement

Arrange for an inert protease to circulate in the blood all the time.

- Pancreas makes proteases used in digestion. Most are inactive until a piece is snipped off by another protease.
- Duplicate a protease gene and mutate its on/off switch so it is turned on in liver. Gets inert protease into circulatory system.
- When cells break, the proteases within them activate this new one, which chops up other proteins.
- Some of the resulting pieces are sticky and clot.

This improves clotting by multiplying the activity of proteases internal to each cell.

Still relies on fact that some chopped up protein pieces are sticky.



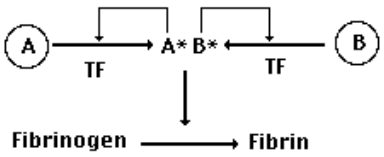
Initial clotting pathway

TF (tissue factor) is a protease inside cells.

A is the inert form of our circulating protease.

A* is the active form.

A* also (weakly) activates other copies of A. (A* and TF are both proteases.)



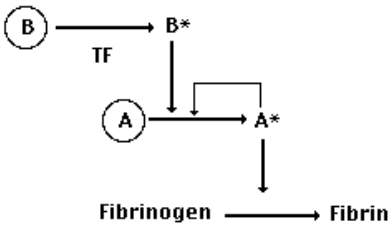
A duplicates to form B

TF activates both A and B.

A* and B* both activate fibrinogen.

A* and B* weakly activate A and B.

No harm, no improvement.



Allow the two proteases to specialize

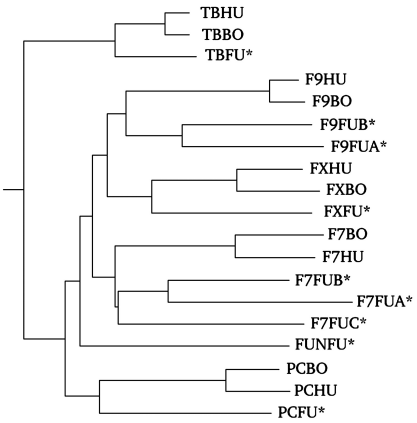
B mutates, becoming less likely to cut fibrinogen but more likely to cut A.

A no longer needs sensitivity to TF.

Favored by selection, because two-stage system accelerates clotting.

Prediction: clotting proteins should have similar amino-acid sequences

- Evolved from a single ancestral protein.
- Different species show the same phylogenetic relationship among clotting proteins.



(Jiang & Doolittle 2003)

Relationships among clotting proteins

Puffer fish

Clotting cascade lacks 3 of components found in human cascade.

Works fine.

Clotting cascade not irreducibly complex.

Sea squirt

A chordate, but not a vertebrate.

No clotting system.

Yet has a fibrinogen-like protein.

Fibrinogen has evolved a different function.

Summary

- The idea of irreducible complexity goes back to Cuvier.
- Refuted by Darwin.
- Type-III secretory system demonstrates that bacterial flagellum isn't irreducibly complex.
- There is a plausible sequence of adaptive evolutionary steps for the blot clotting cascade.
- Phylogeny supports this evolutionary hypothesis.
- Puffer fish proves that the cascade isn't irreducibly complex.