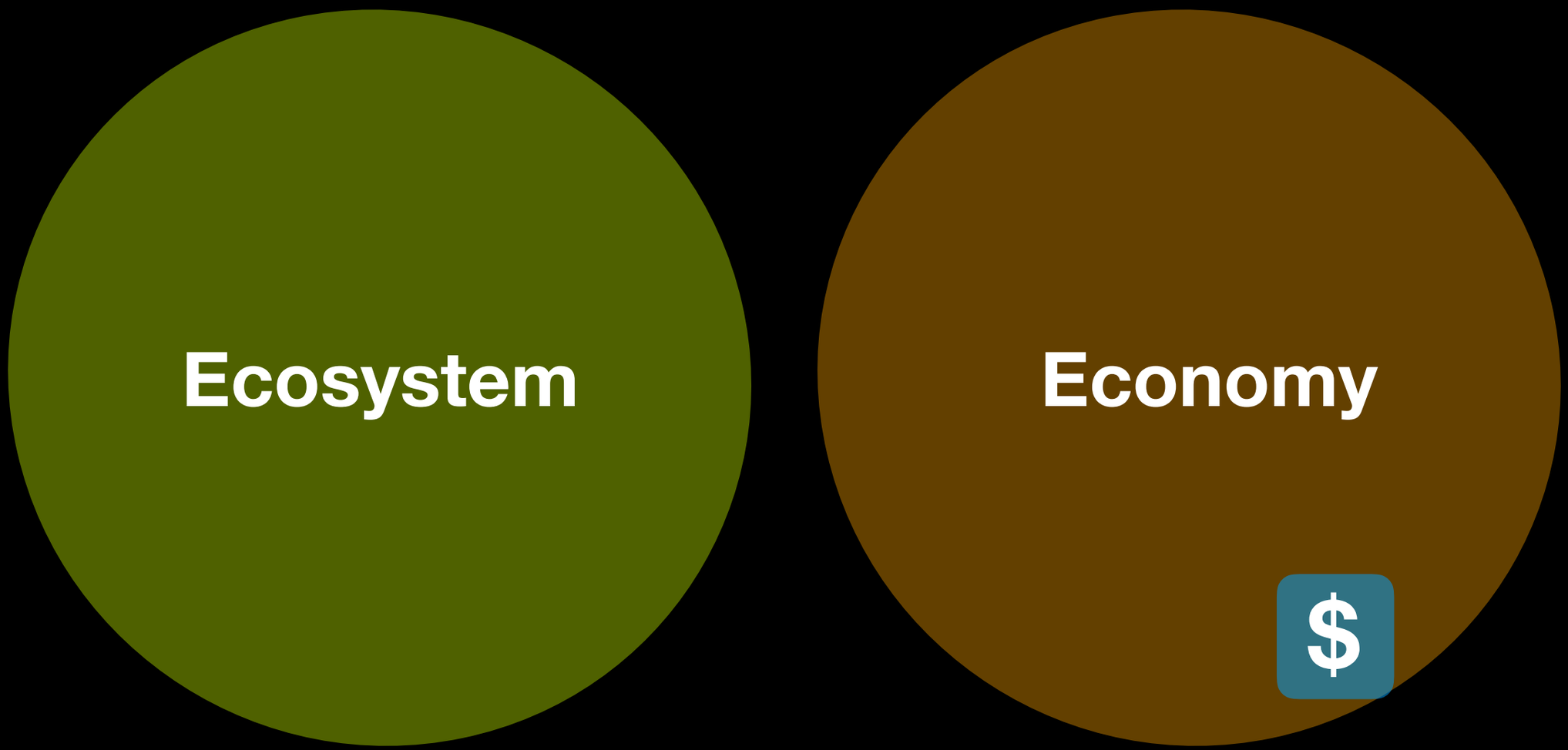
Why Information is the fundamental Factor of Production and what that means for us.

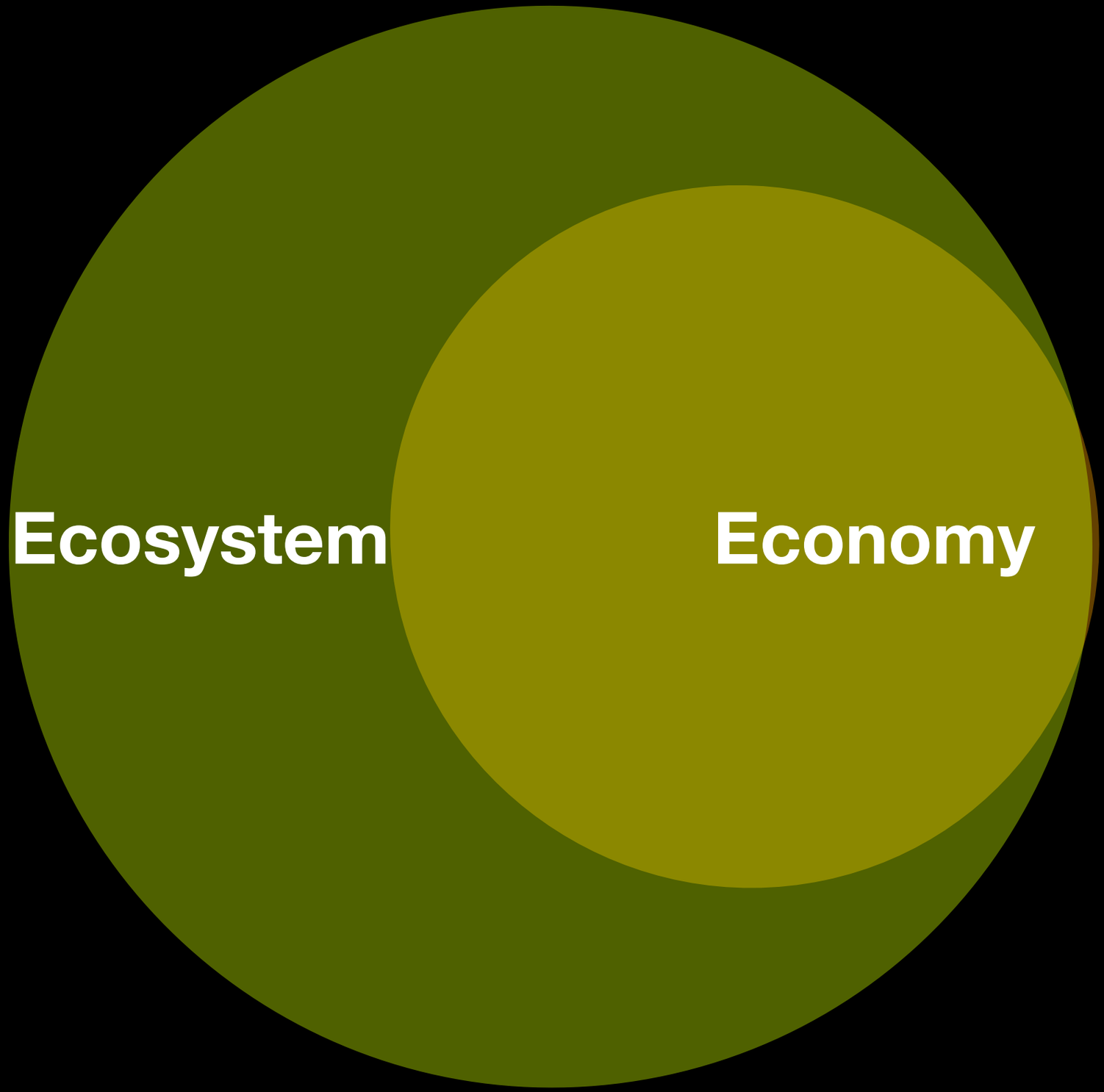
NASA

Keith Farnsworth
Queen's University Belfast

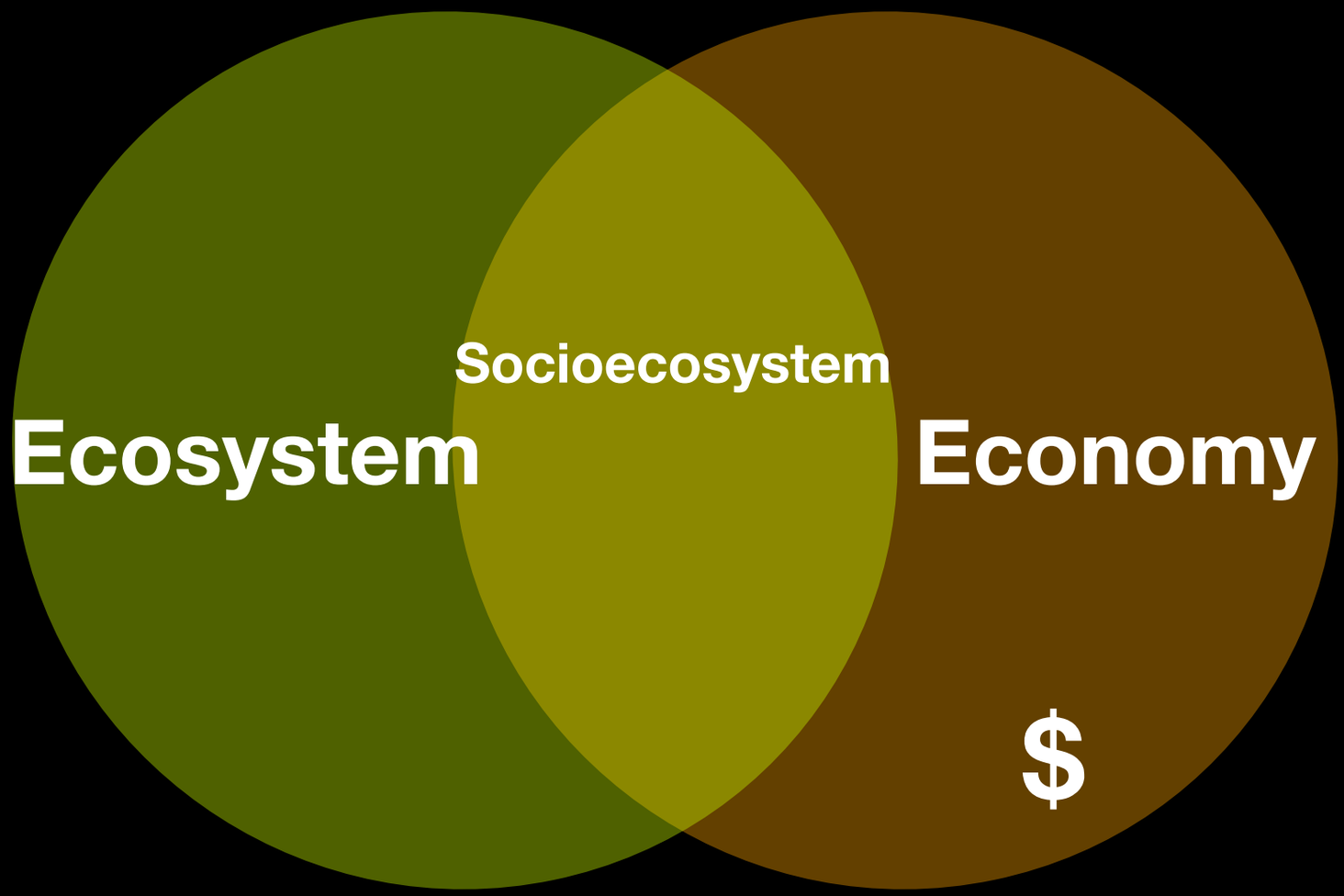
The conventional view



Aim of Ecological Economics

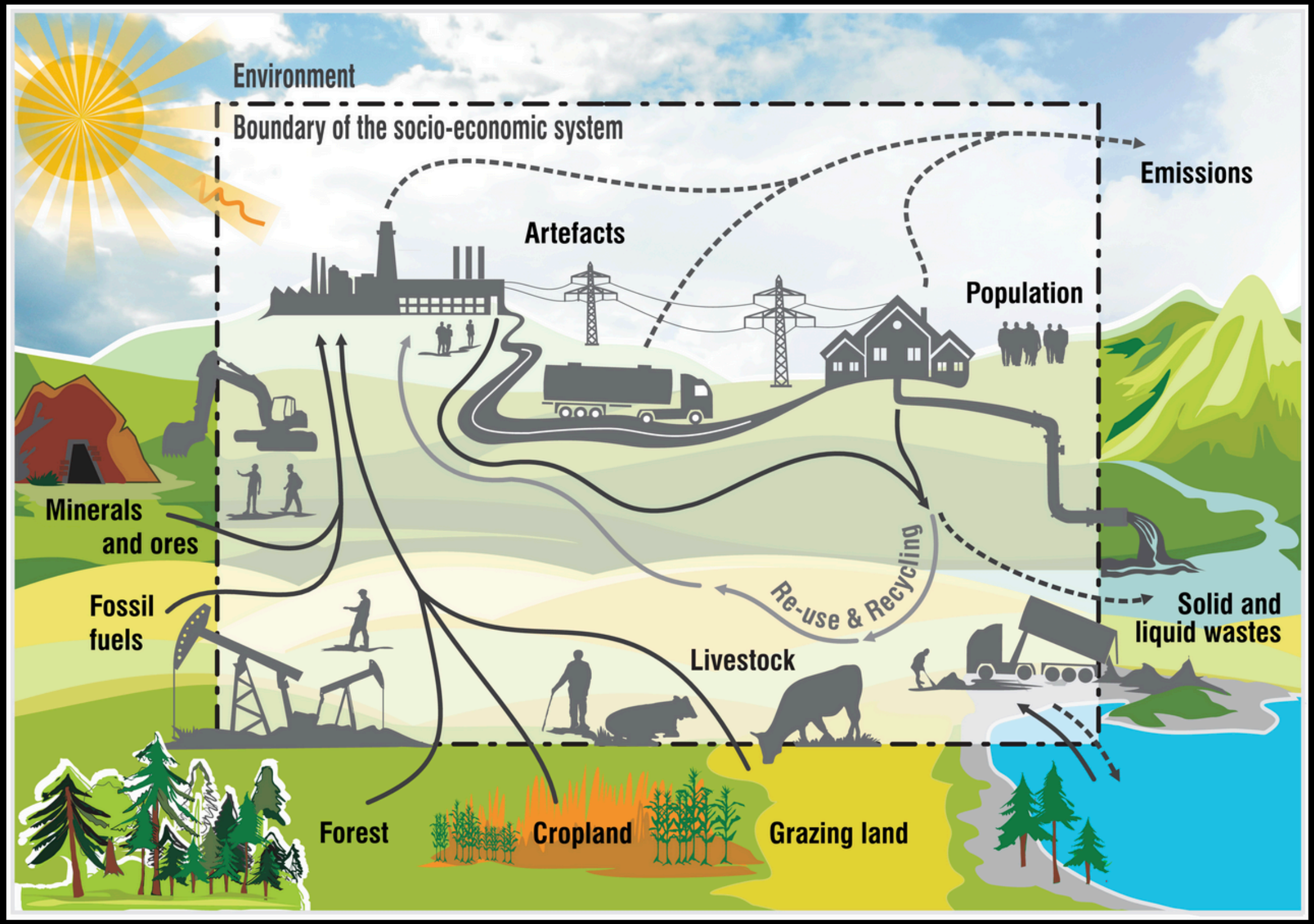


Ecological economics: so far

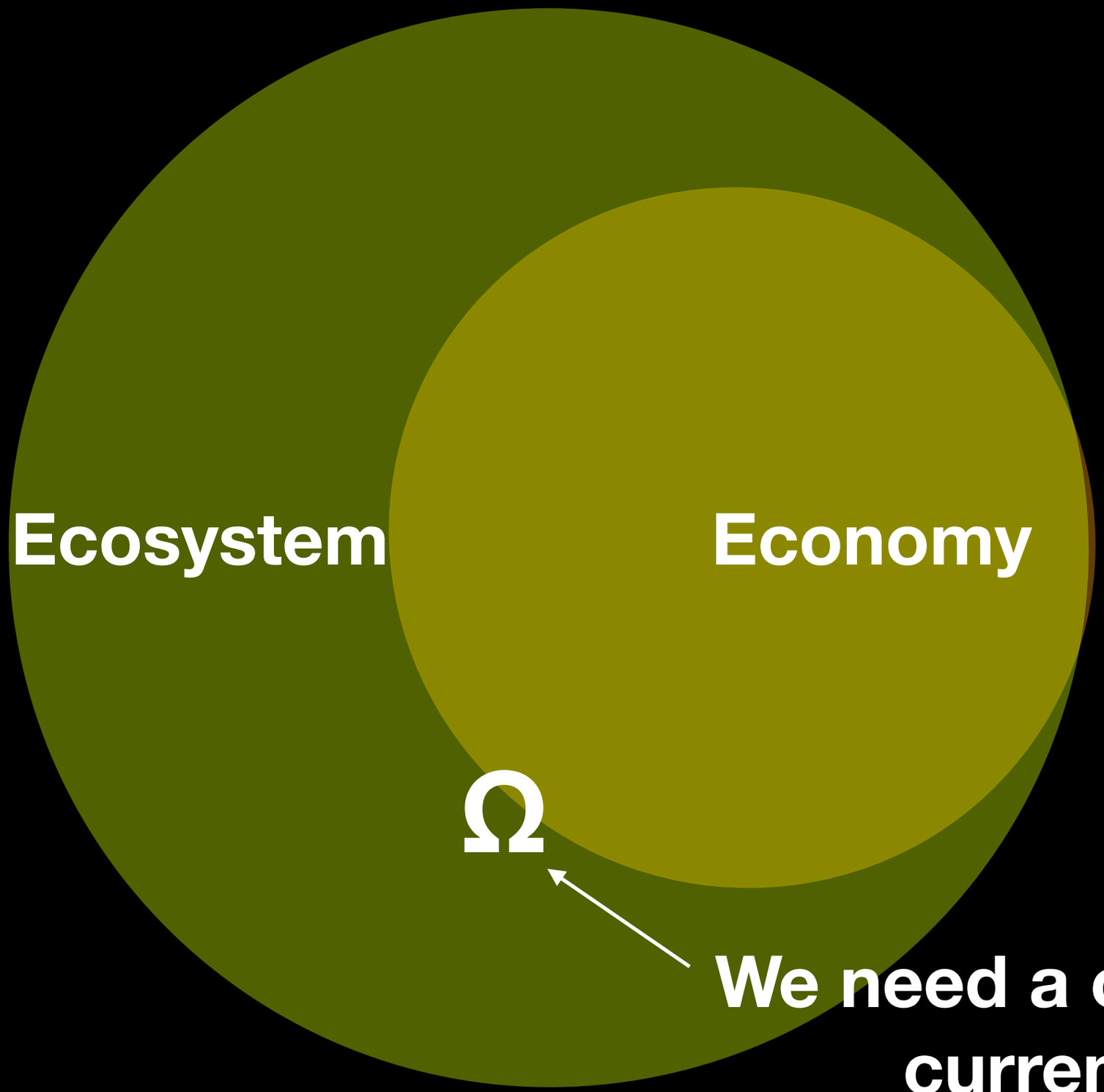


“socioeconomic metabolism”

Haberl, H., Wiedenhofer, D., Pauliuk, S. *et al*. Contributions of sociometabolic research to sustainability science. *Nat Sustain* **2**, 173–184 (2019). https://doi.org/10.1038/s41893-019-0225-2

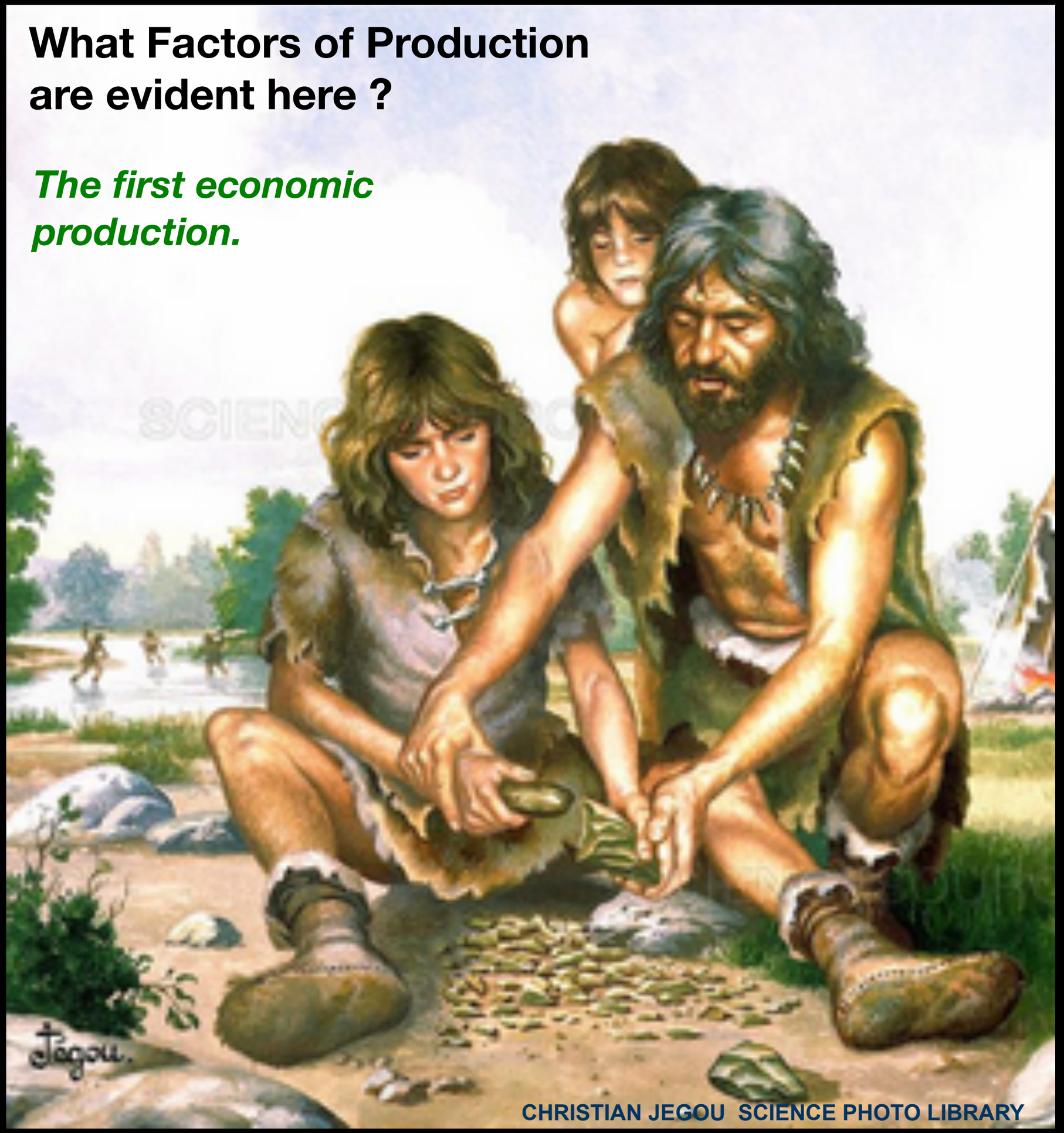


Let’s think critically about this diagram


Ecosystem
Economy
Ω
We need a common currency

What Factors of Production are evident here ?

The first economic production.



Production always entails investing material with information

Every knap of the tool leaves a permanent record of the toolmaker's intention.

It entails the processing of information in the toolmaker's mind and informed control of their body.

The toolmaker reproduces the information by teaching their offspring.

Fabrication (in this case *subtractive formation*)

Raw flint

ohiodnr.gov

Informed flint

https://donsmaps.com/schleswigneanderthal.html

Random shape

Constrained shape

As well as fabrication, production involves assembly.

Random assembly

pngtree.com

Constrained assembly

Assembling = ***additive formation (investing with information)***

lindagge.com

Random assembly

pngtree.com

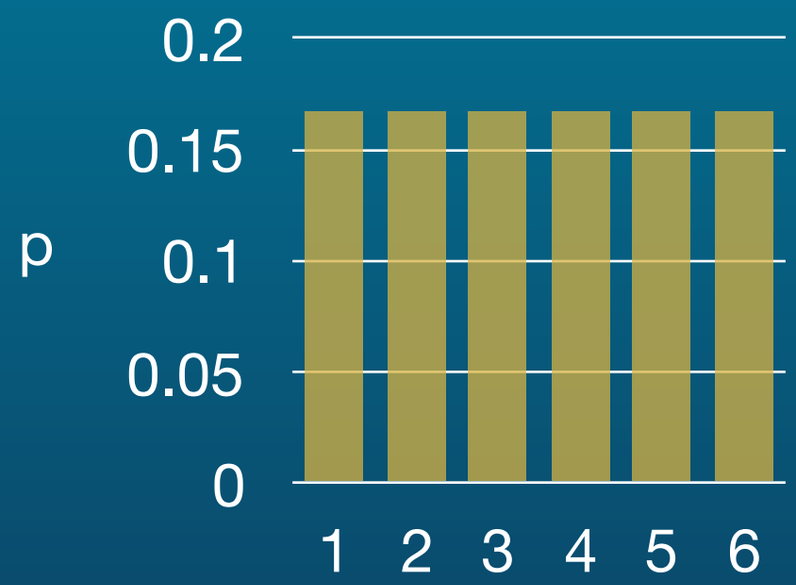
Constrained assembly

Information is the constraint of randomness. So if we get this particular arrangement of bricks, rather than random, we know it is informed.

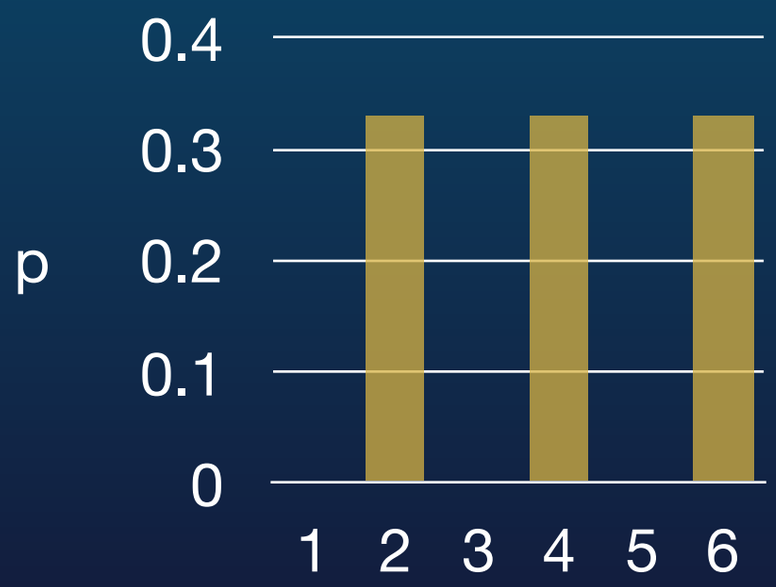
lindagge.com

Information is the constraint of randomness

Information is the constraint of randomness

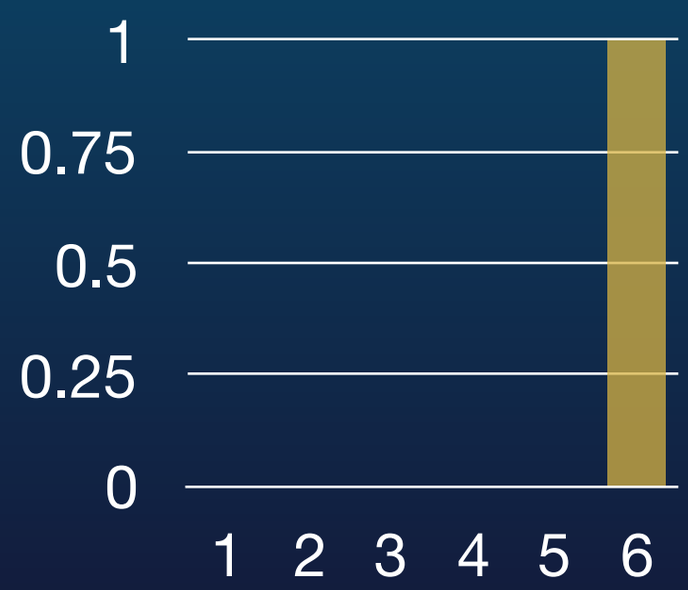


if you knew nothing
it's free to be anything

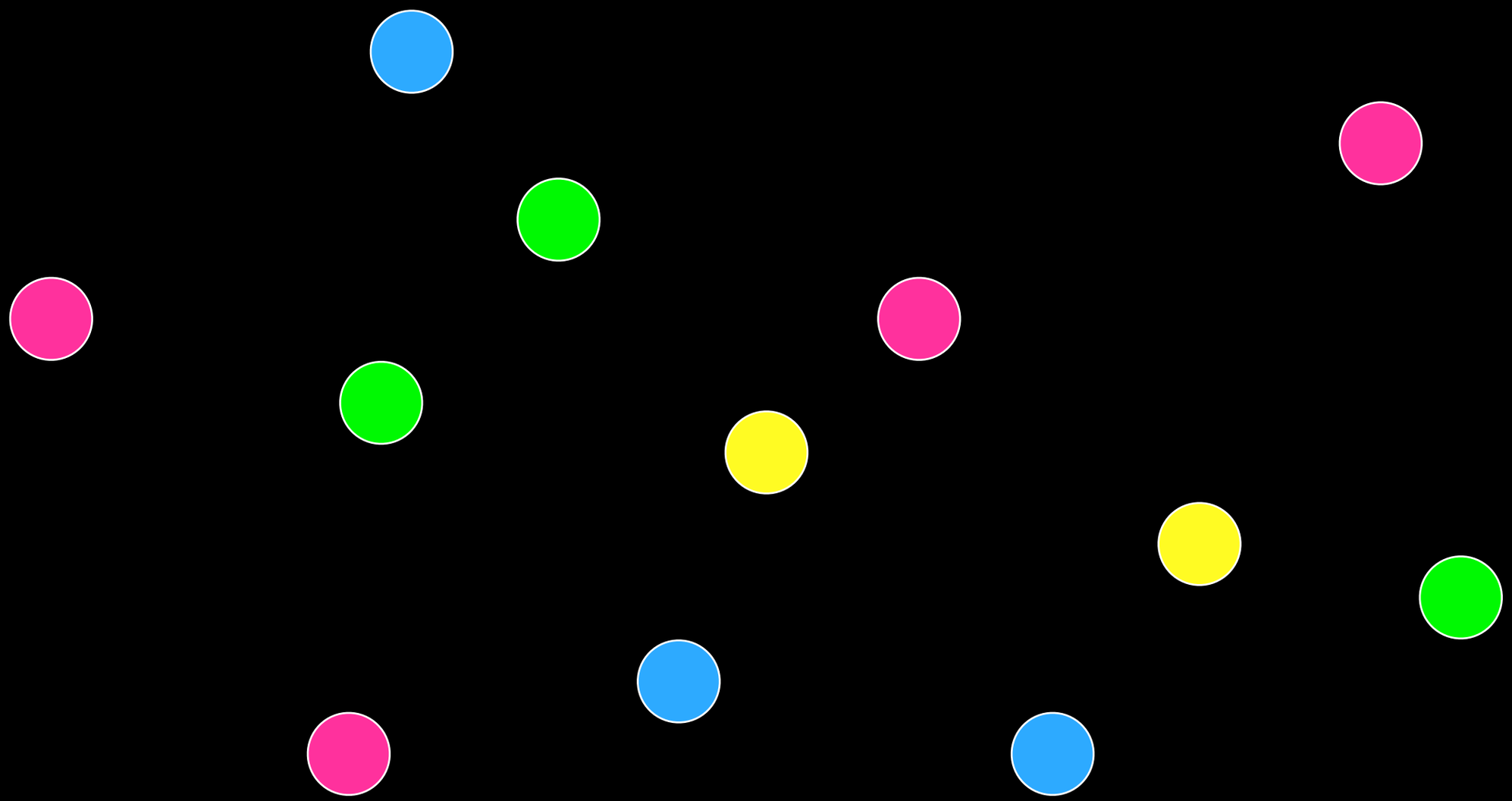


if you knew
it was an
even number,
its constrained
to be even.

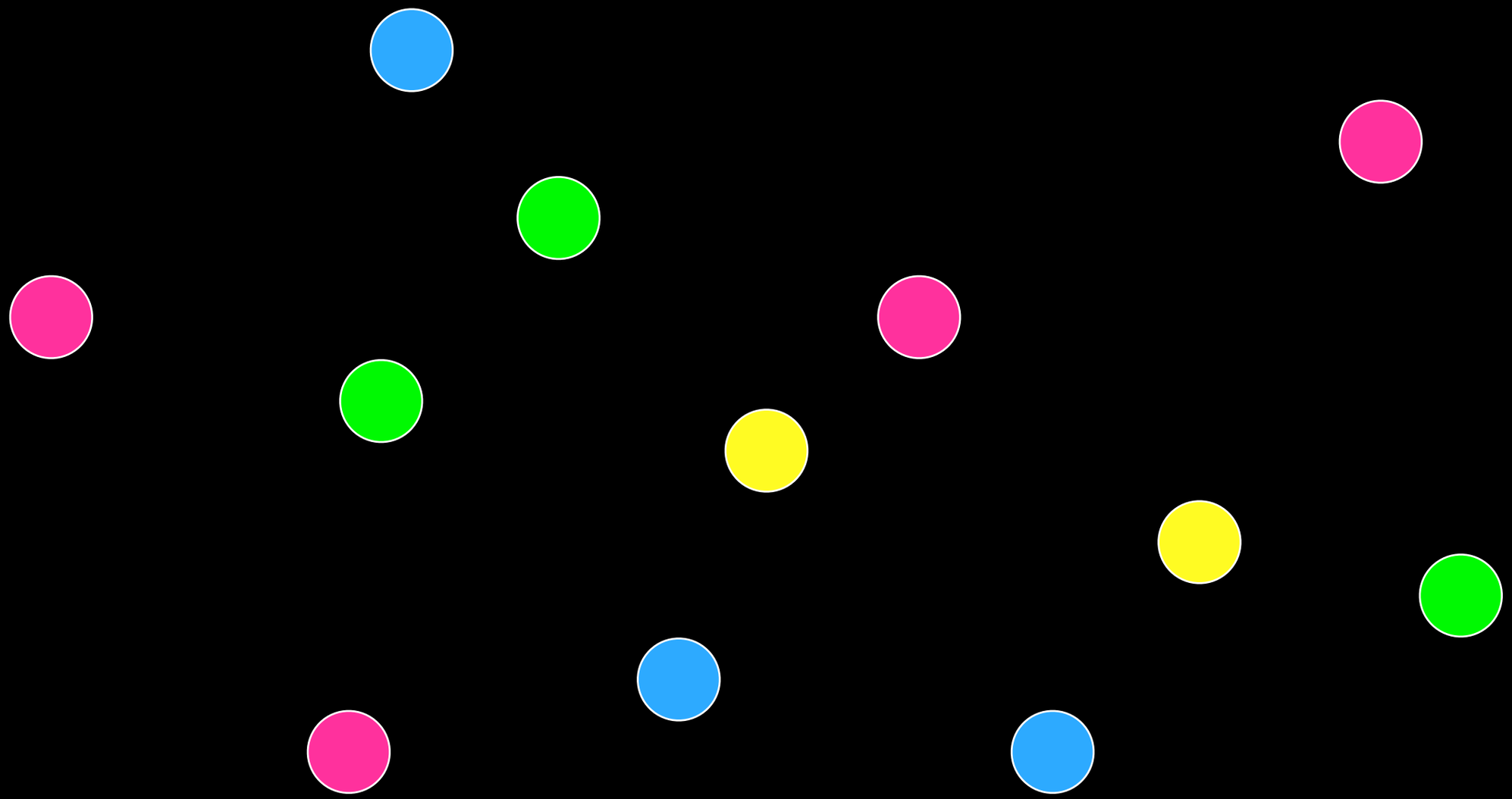
You know it was a 6



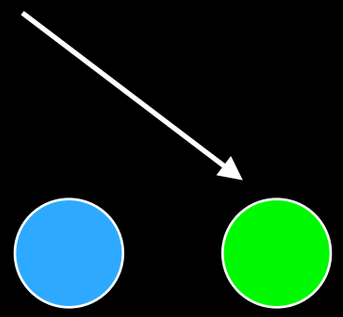
Constraint on degrees of freedom



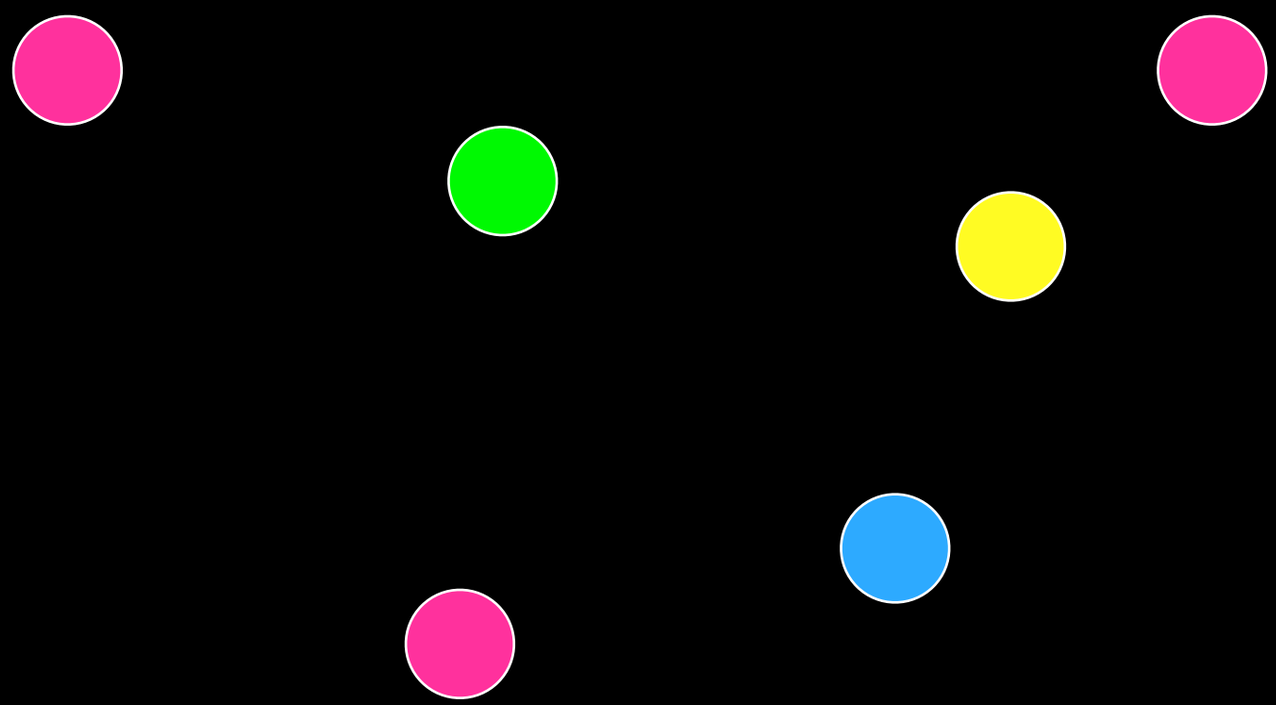
This is how information is made



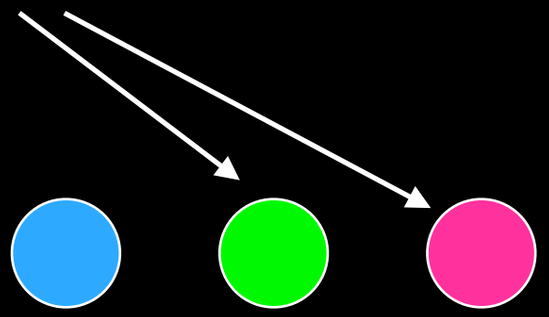
Constrain one



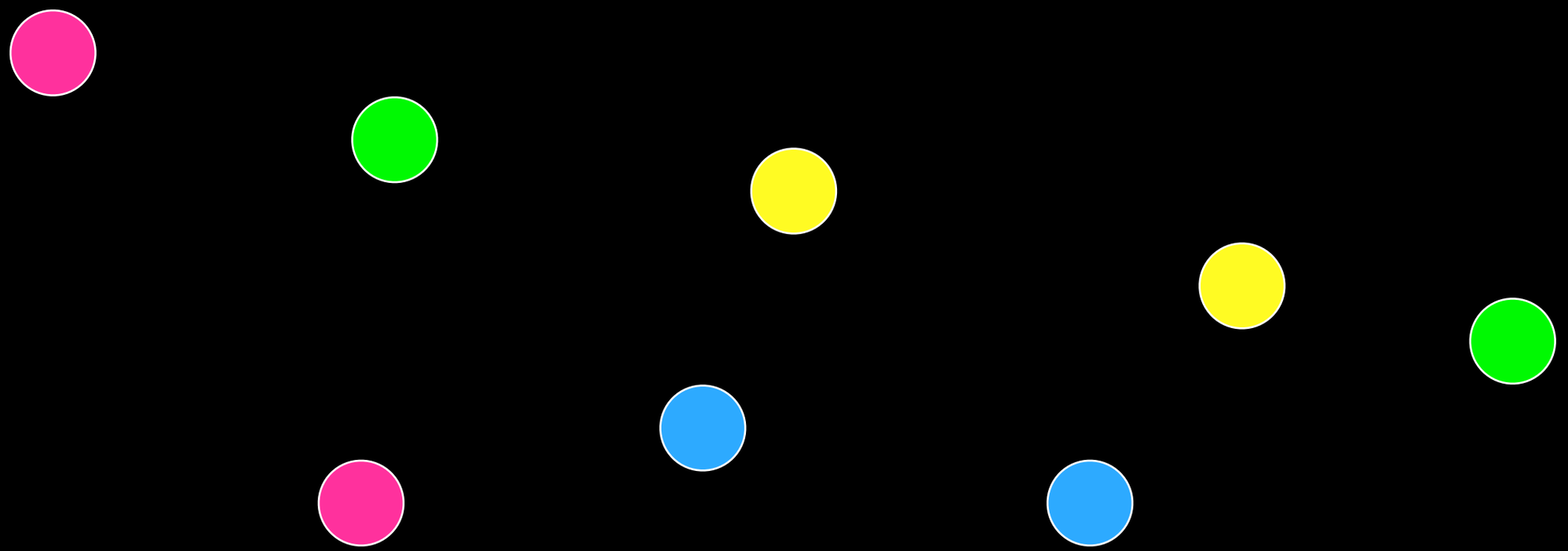
p=0.2



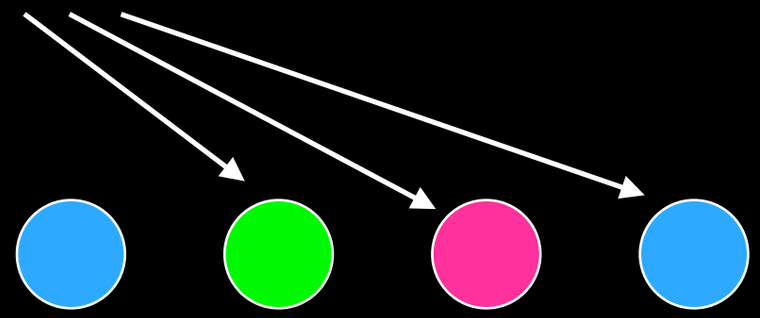
Constrain two



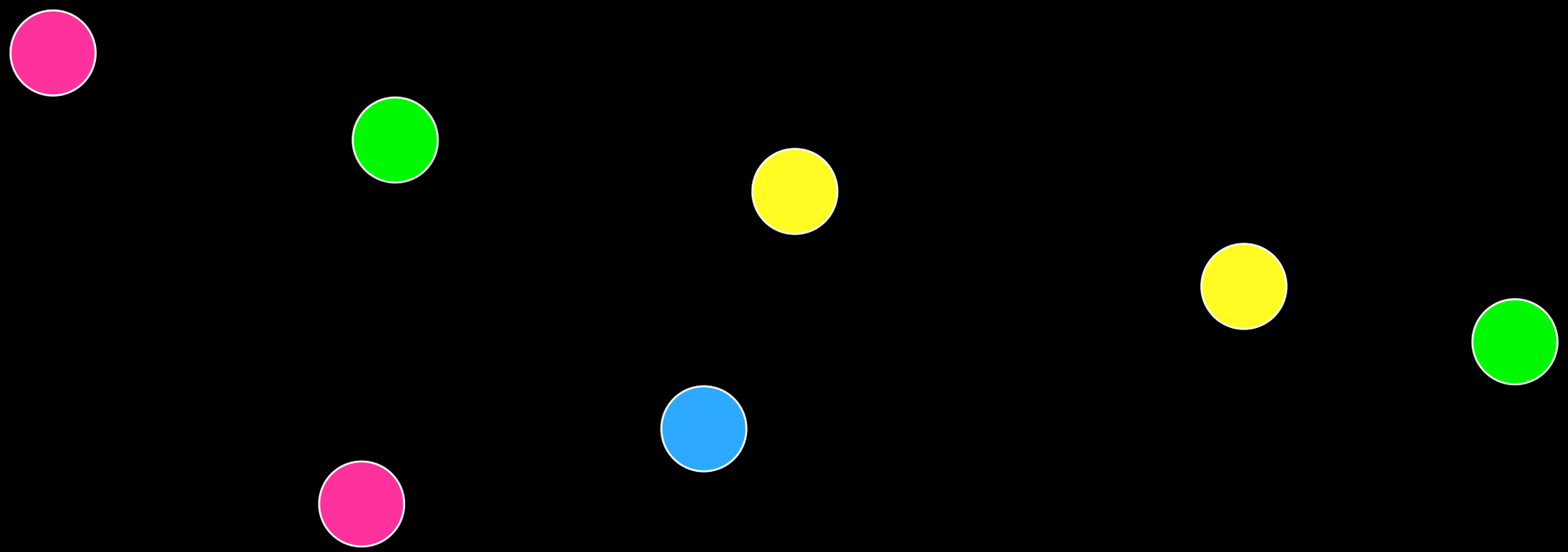
p=0.04



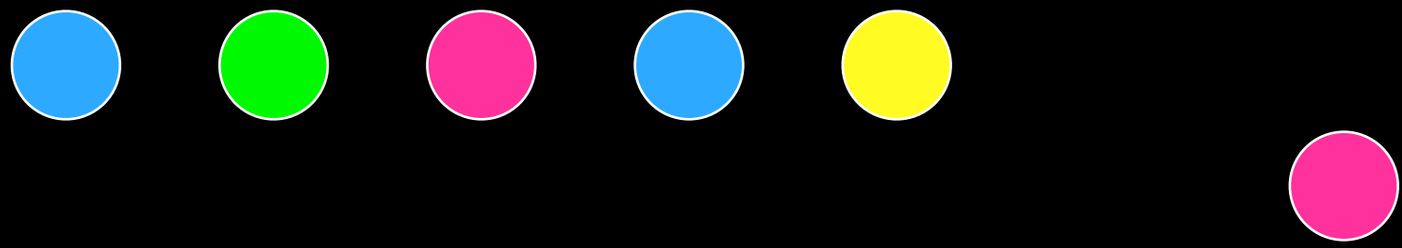
Constrain three

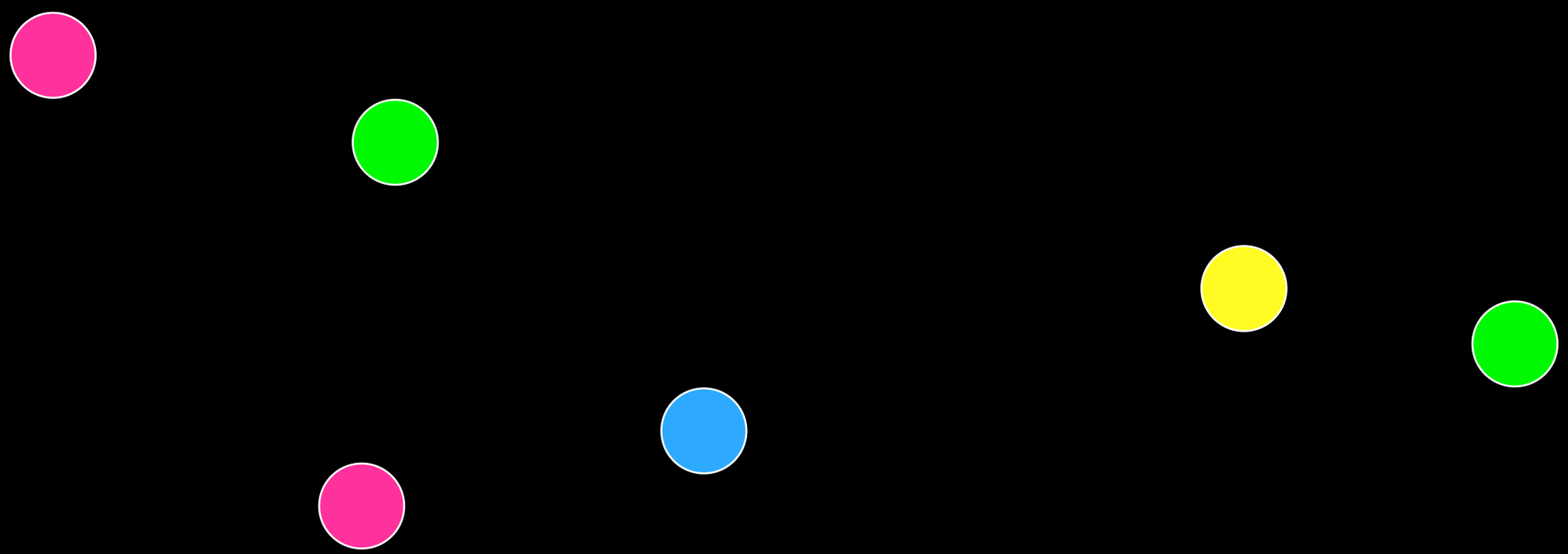


p=0.008

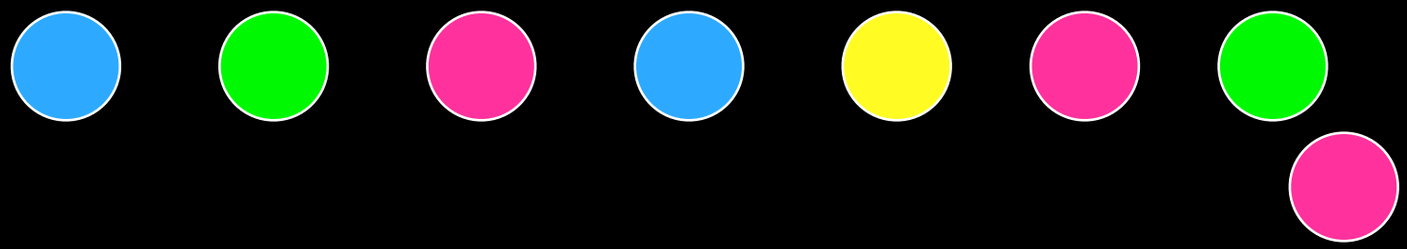


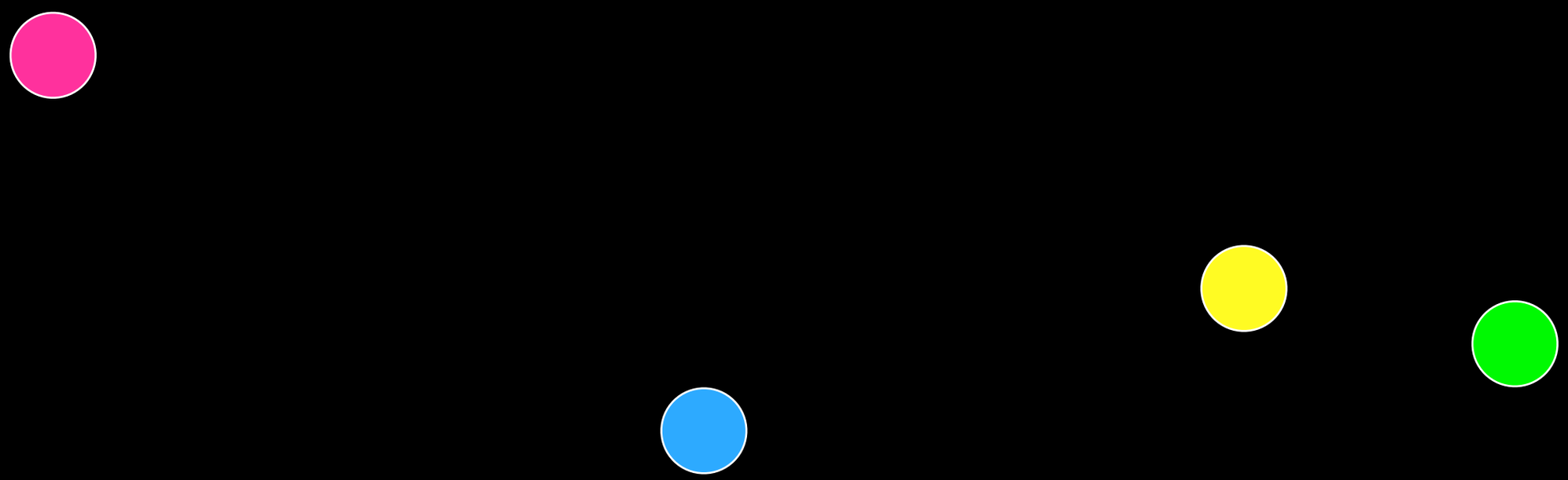
p=0.0016



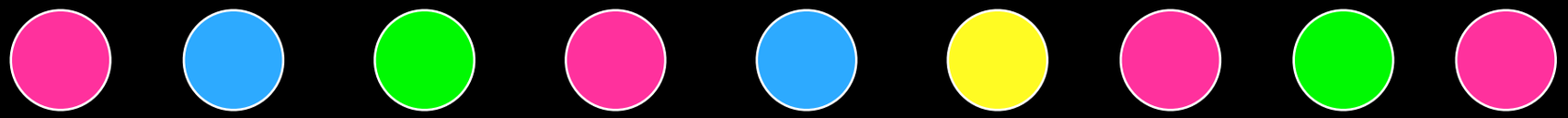


p=0.000012





p=0.000000052



Making an increasingly improbable pattern by constraint

Information: an improbable pattern

p=0.0000000004

Information is pattern.

One pattern from among many possible.

The unit of information

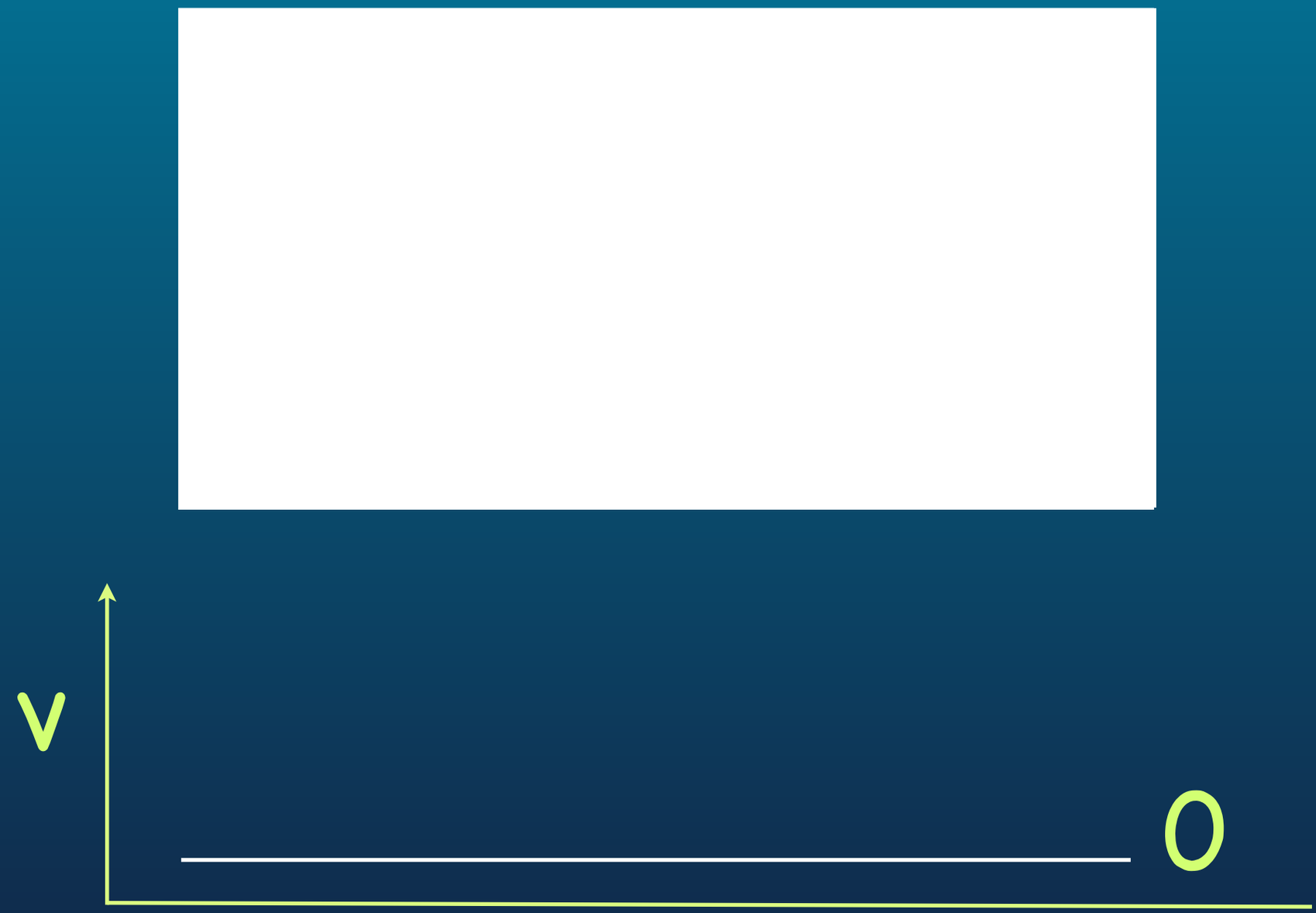
1 | 0

presence / absence

True / False

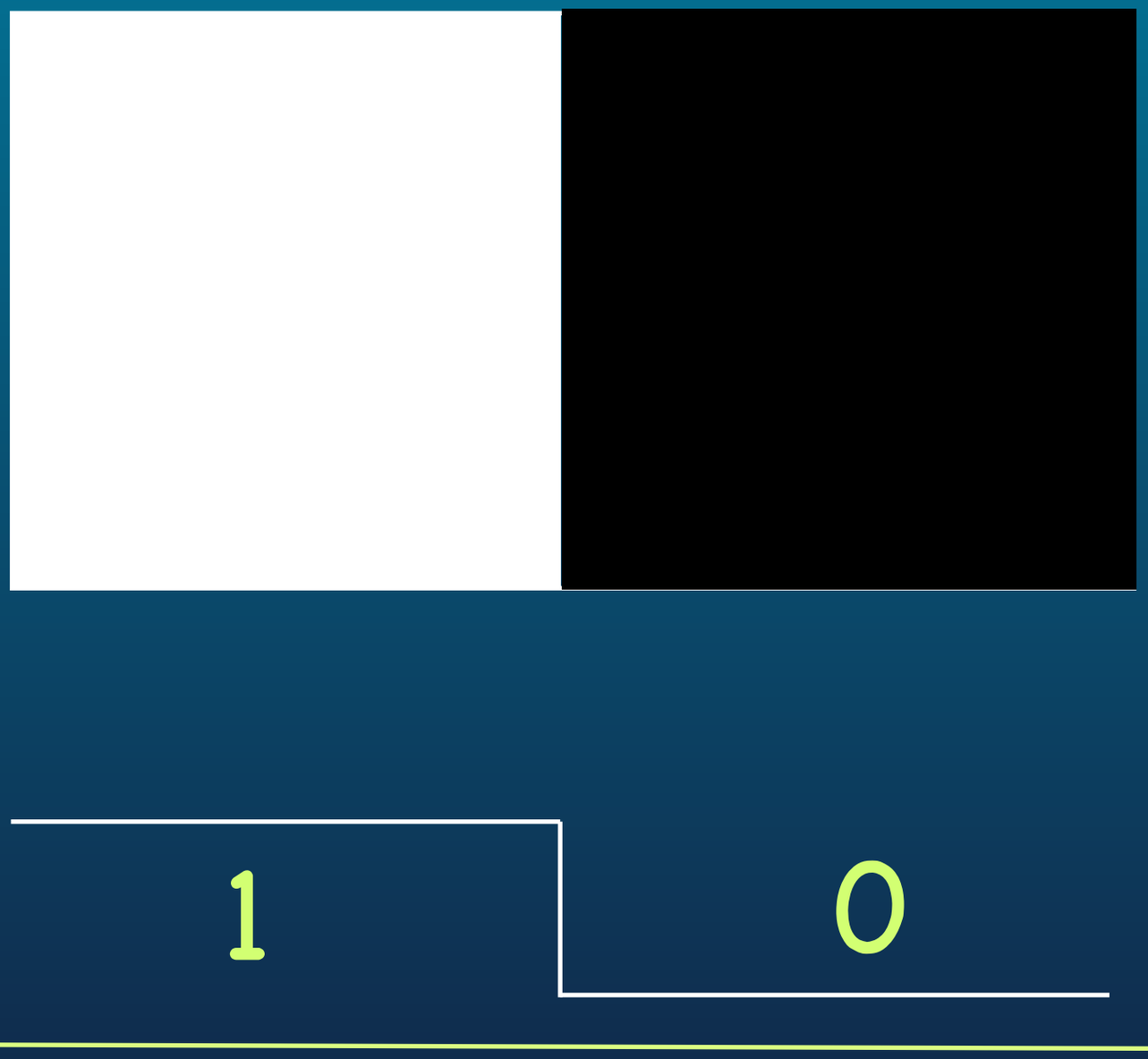
A binary bit, of course

Take a blank sheet of paper...

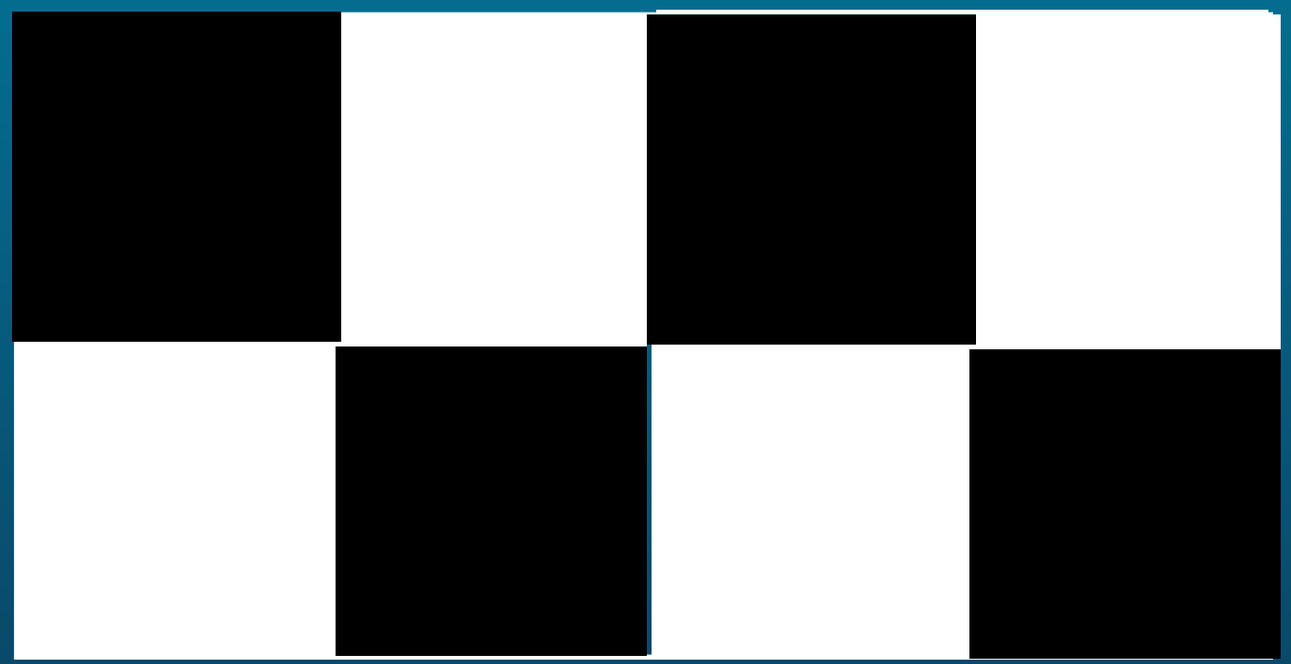


There is no information here

A difference is the unit of information



A set of differences makes a pattern



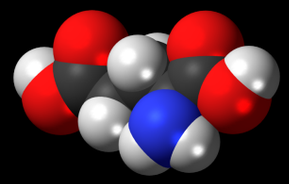
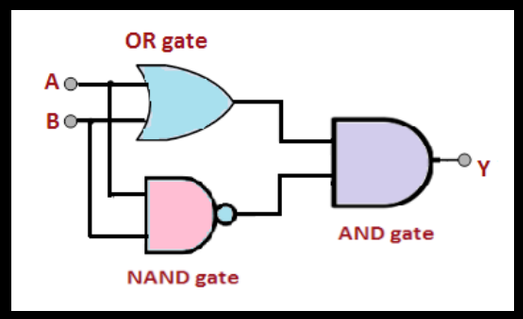
Pattern is information

Landauer's Dictum

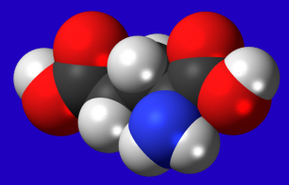
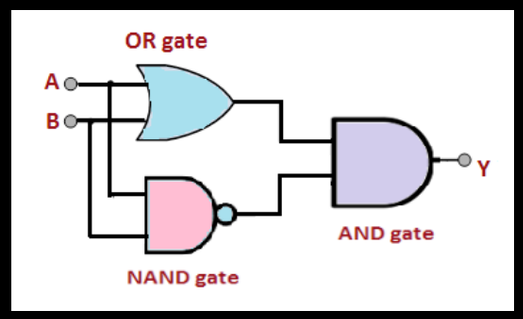
Information is physical

It is in the patterns made by the distribution of matter

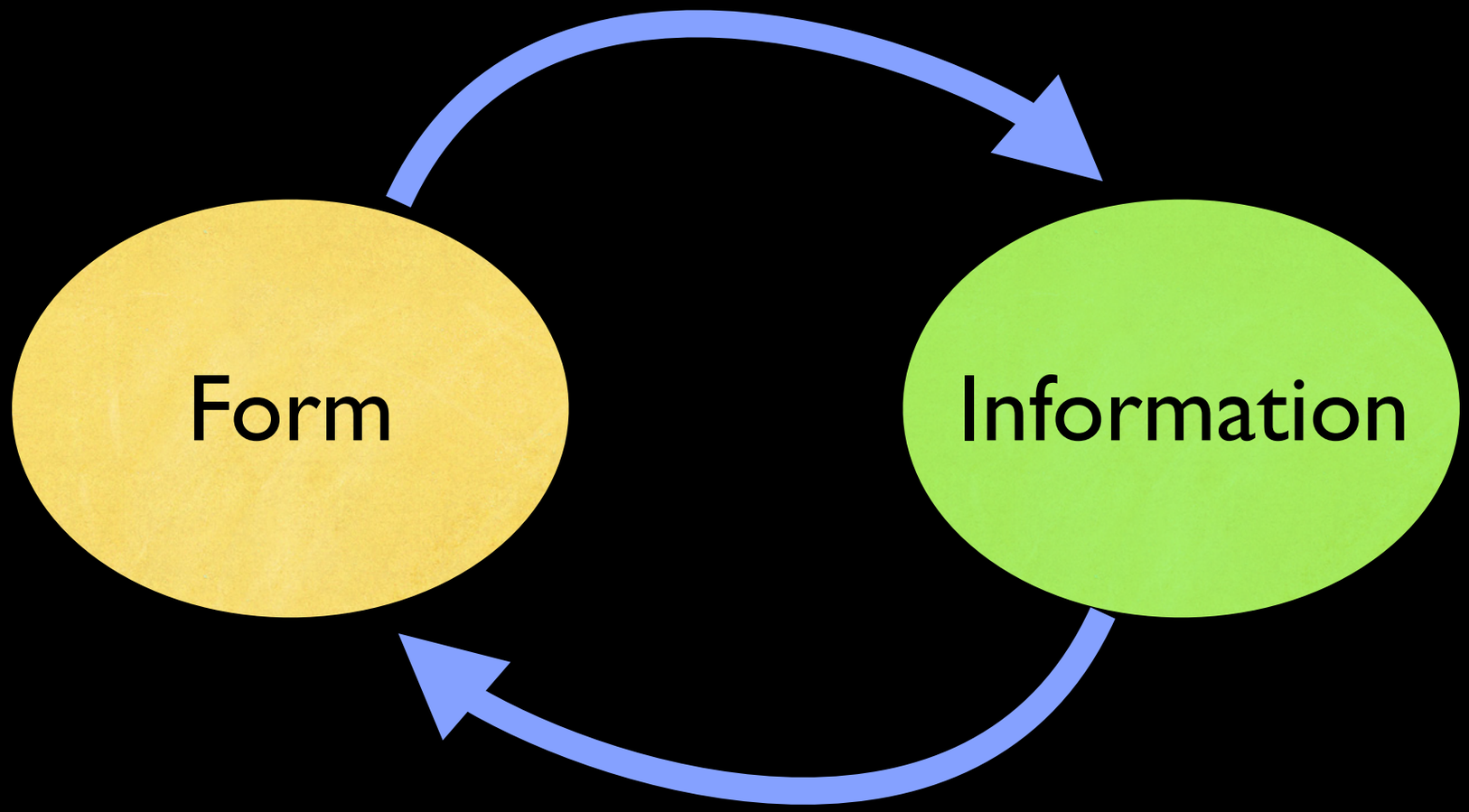
Three notions of Information

Physical Information		**Embodied in form**
Formal Information		**Disembodied logic**
Statistical Information	$H = -\sum_{i=0}^{n} p_i \log(p_i)$	**statistical relations among data**

Three kinds of Information

Physical Information		**Embodied in form**
Formal Information		**Disembodied logic**
Statistical Information	$H = -\sum_{i=0}^{n} p_i \log(p_i)$	**statistical relations among data**

Form embodies information



Information determines form

A creative recursion

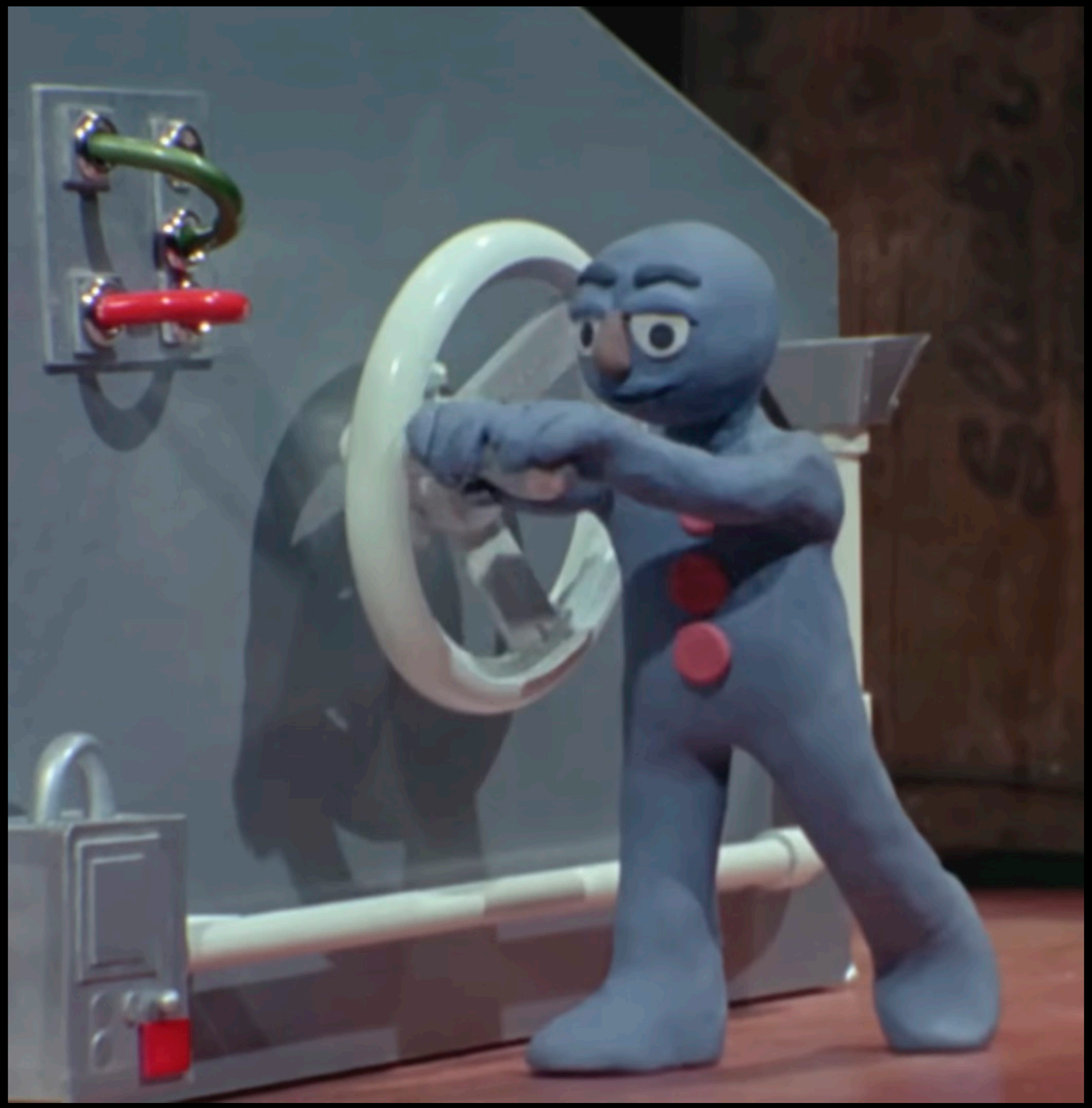
+ Information

Gives us...

Morph & Chas by Tony Hart (BBC)

Form

Now we have forms, let's do work



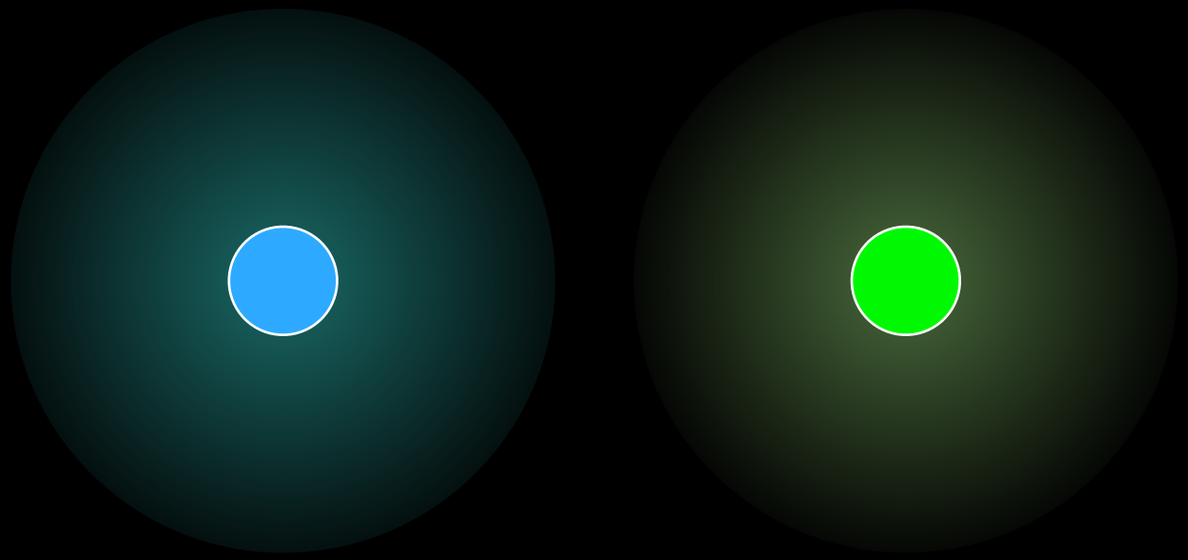
from The Amazing Adventures of Morph. Tony Hart 1980

Doing, not just being.

doing always involves physical causation

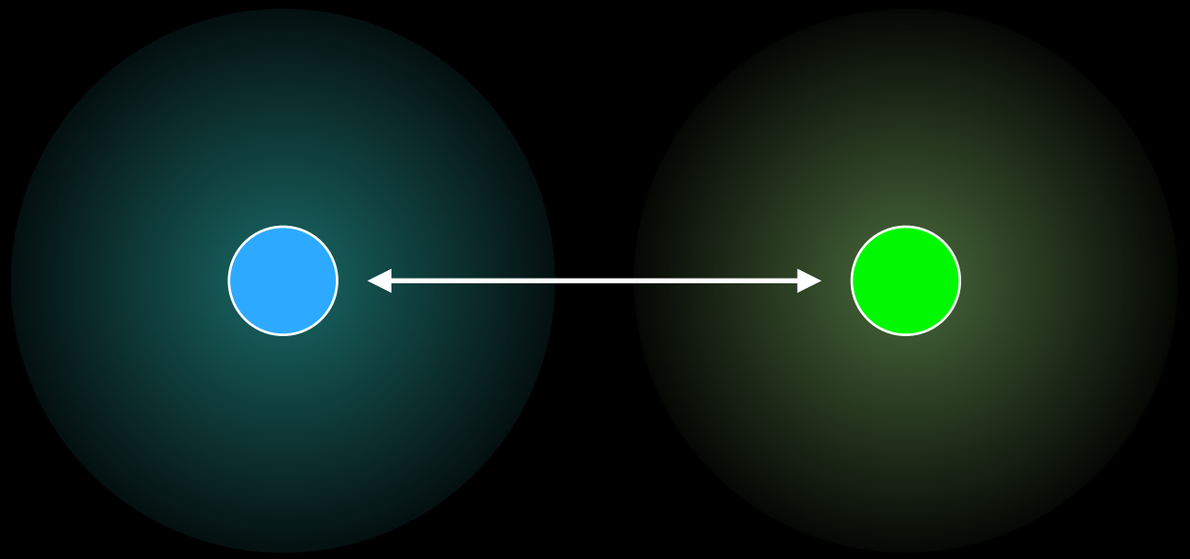
Physical Cause

Every fundamental particle has an associated forcefield



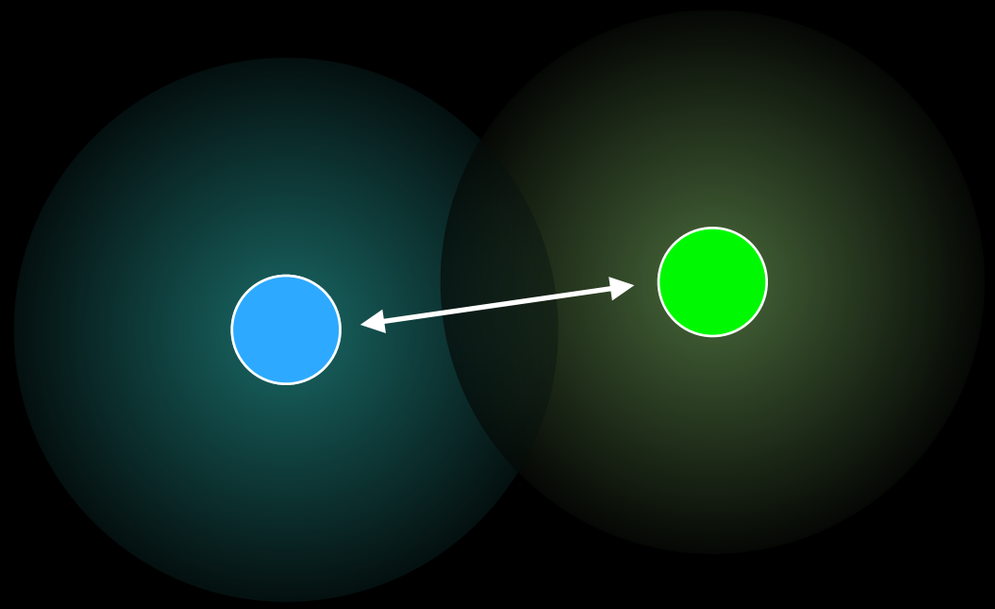
Things happen, only when these forcefields interact.

Physical Cause



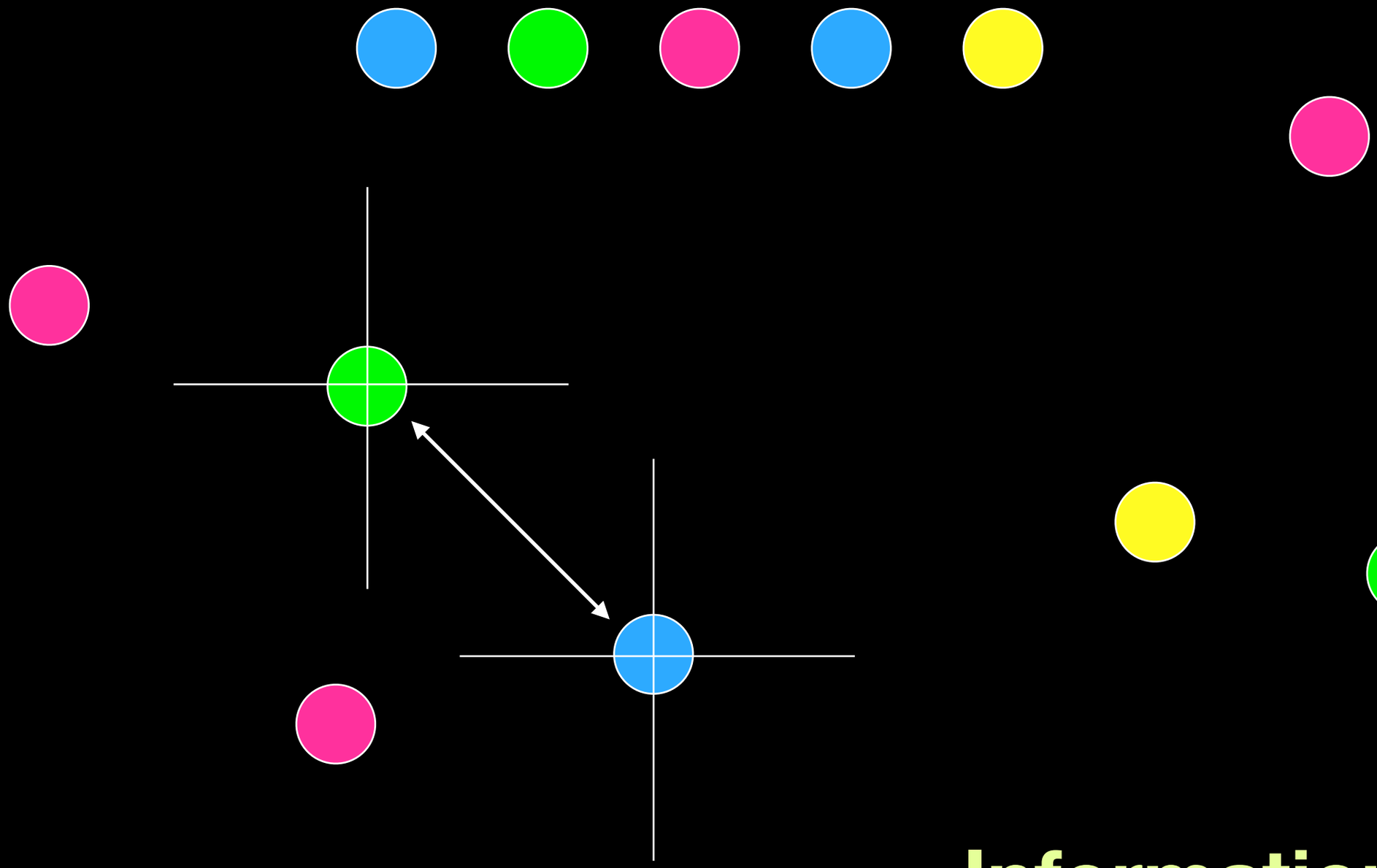
Exactly what happens, depends on their relative locations

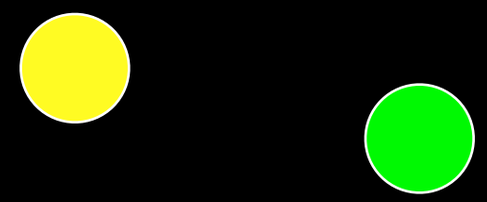
Physical Cause



Exactly what happens, depends on their relative locations

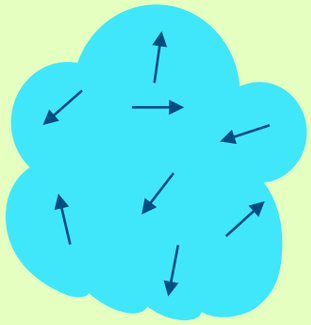
… and their relative locations are…



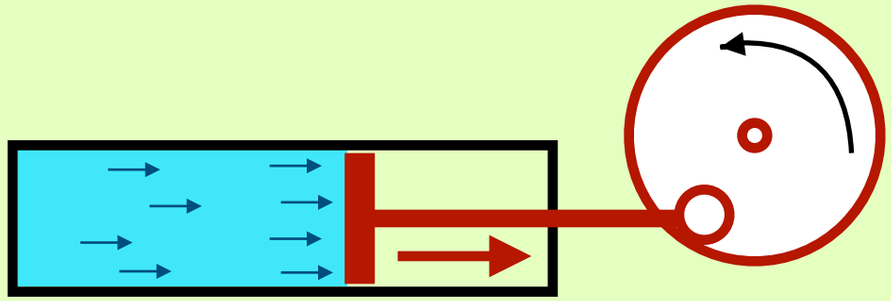


Information

To cause anything to happen, physical forces must be organised by constraining them.



unconstrained forces
= just heat



information provides constraint.

now
*force can do **work***
= efficient cause.

All constraints to physical forces arise from physically embodied information.

Cause = force + information.

So now we have some axioms:

1. Production always entails investing material with information.

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2. The only way to do that is through physical causation.

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2. The only way to do that is through physical causation.
3. Physical causation necessarily entails doing physical work.

1. Production always entails investing material with information.
2. The only way to do that is through physical causation.
3. Physical causation necessarily entails doing physical work.
4. Thus, production requires physical work to be done.

Biotic Growth is Production

Investing material with information - the information of life

This is true of all life:

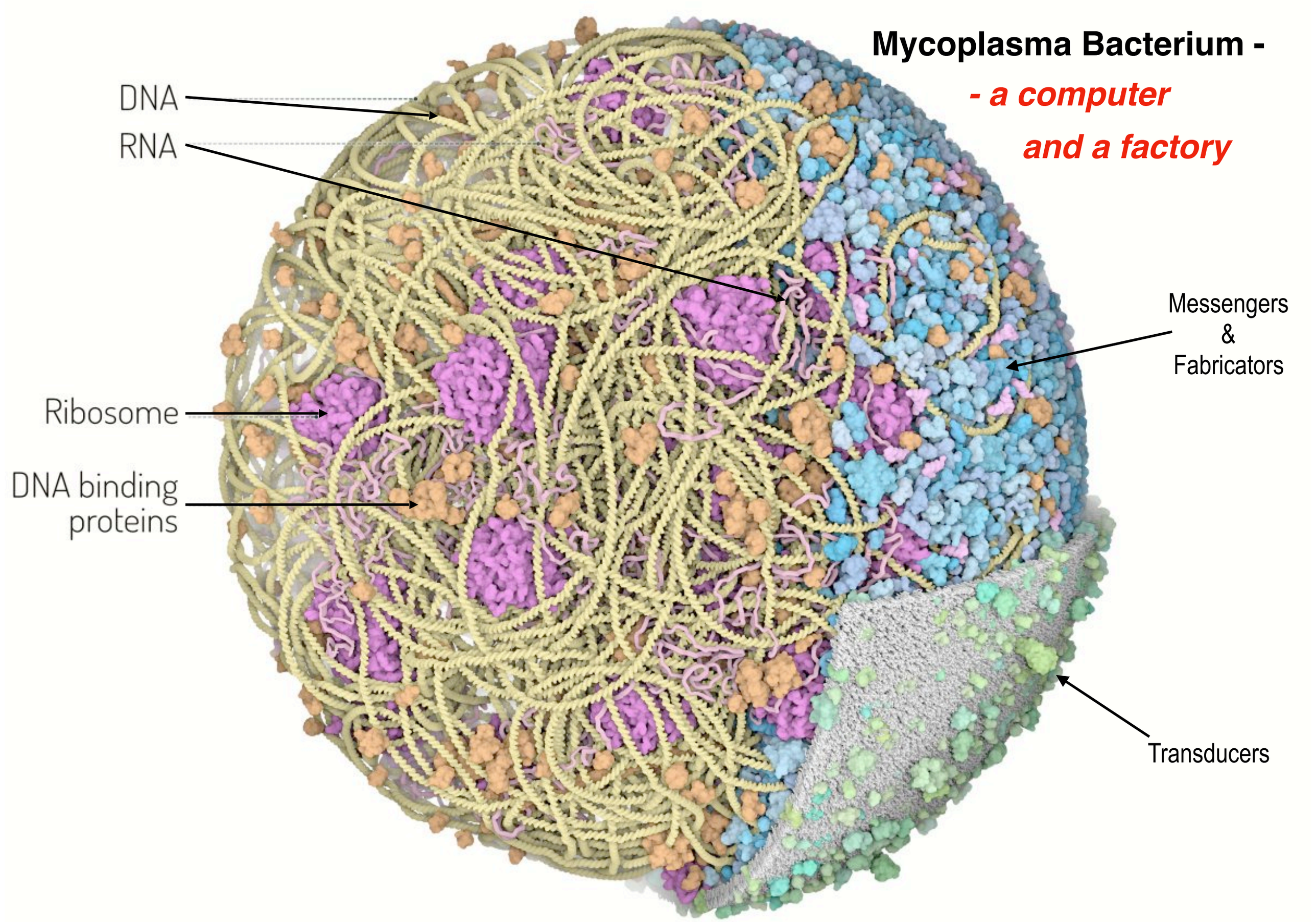
Production of new cells is work which entails investing biological matter with information.

from Bierenbroodspot et al., 2025, Current Biology 35, 5071–5080

Mycoplasma Bacterium -

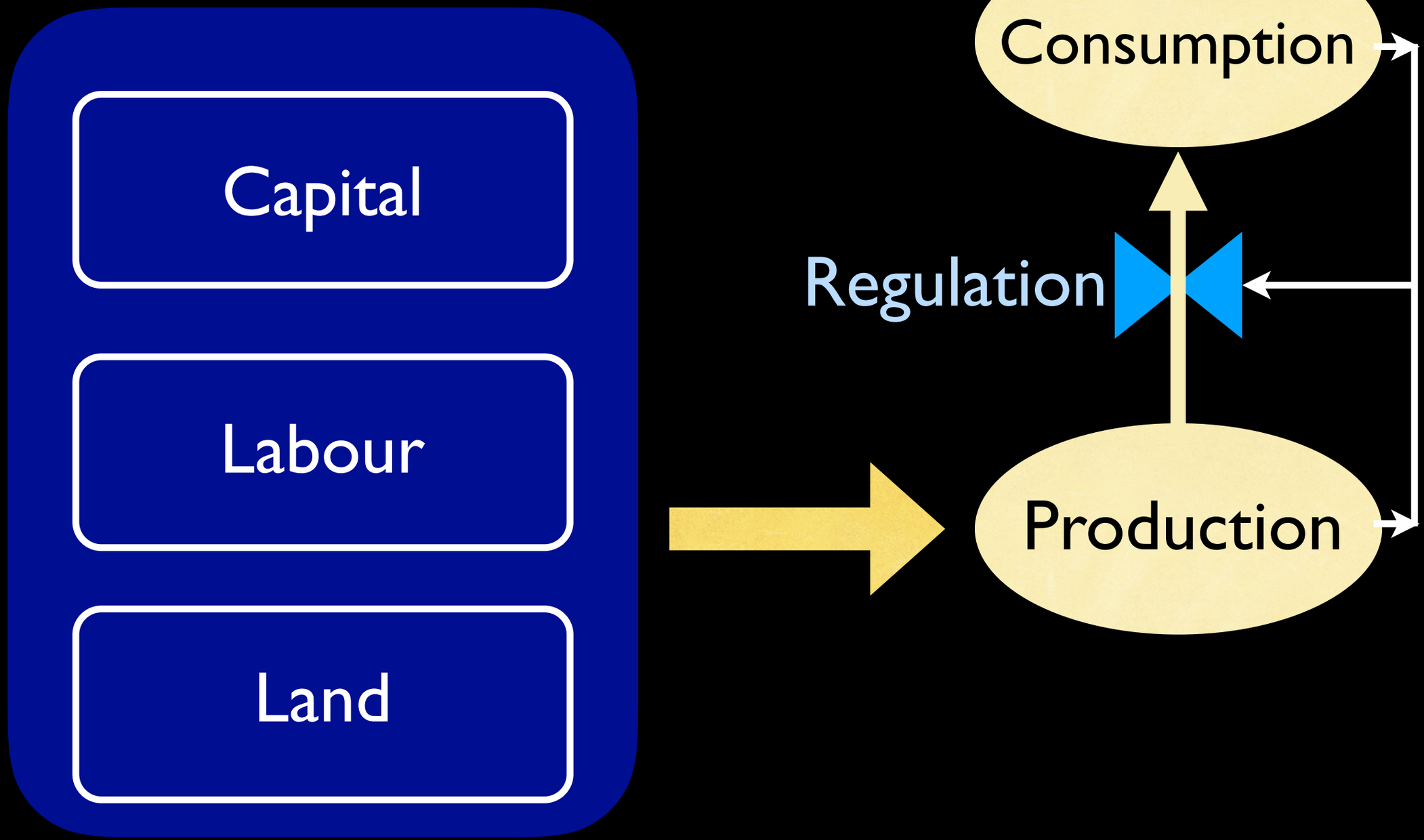
- a computer

and a factory



David Goodsell and Martina Maritan 2022

Traditional 3 Factors



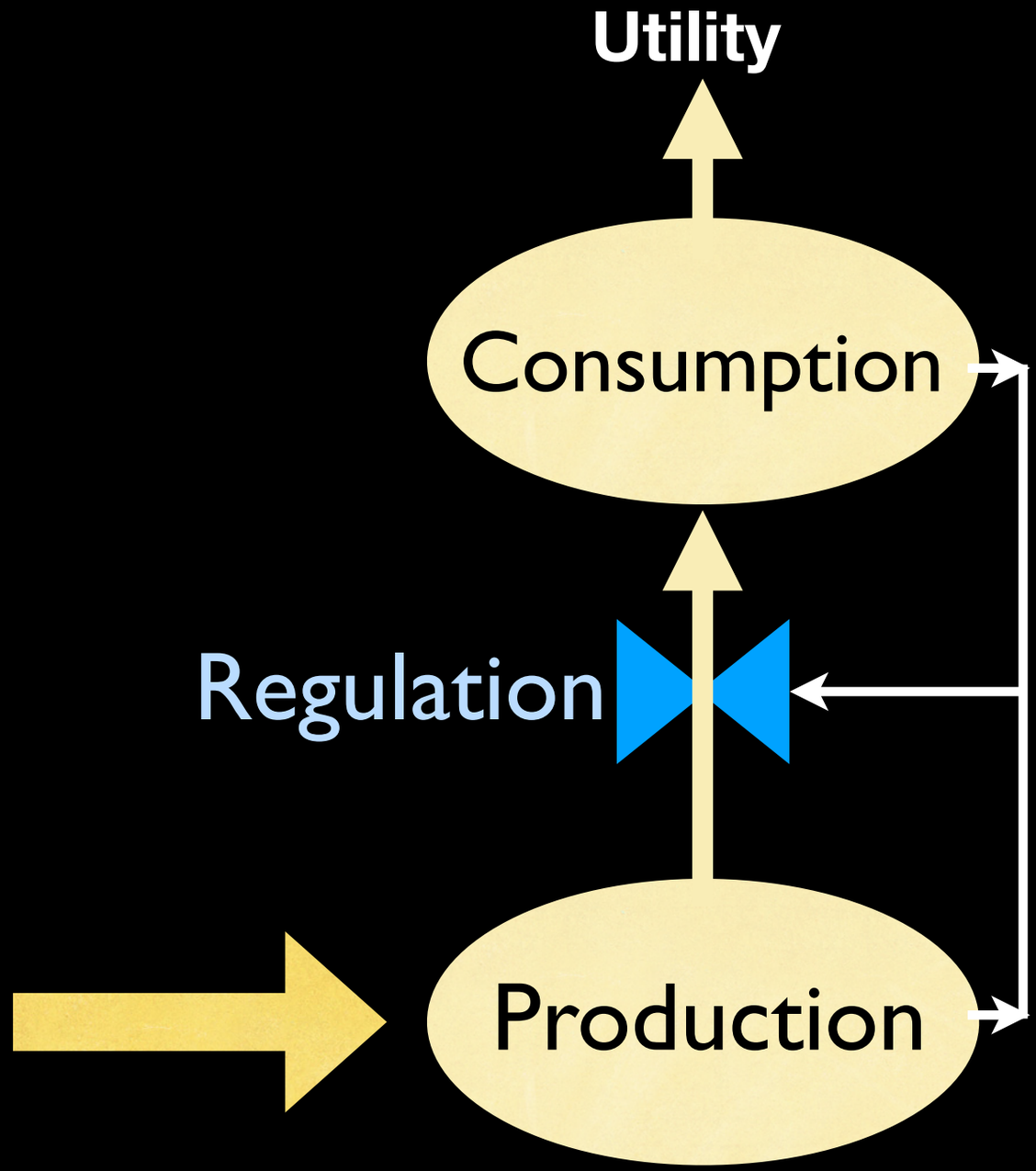
Some add
"entrepreneurship"

Capital

Labour

Land

Entrepreneurship



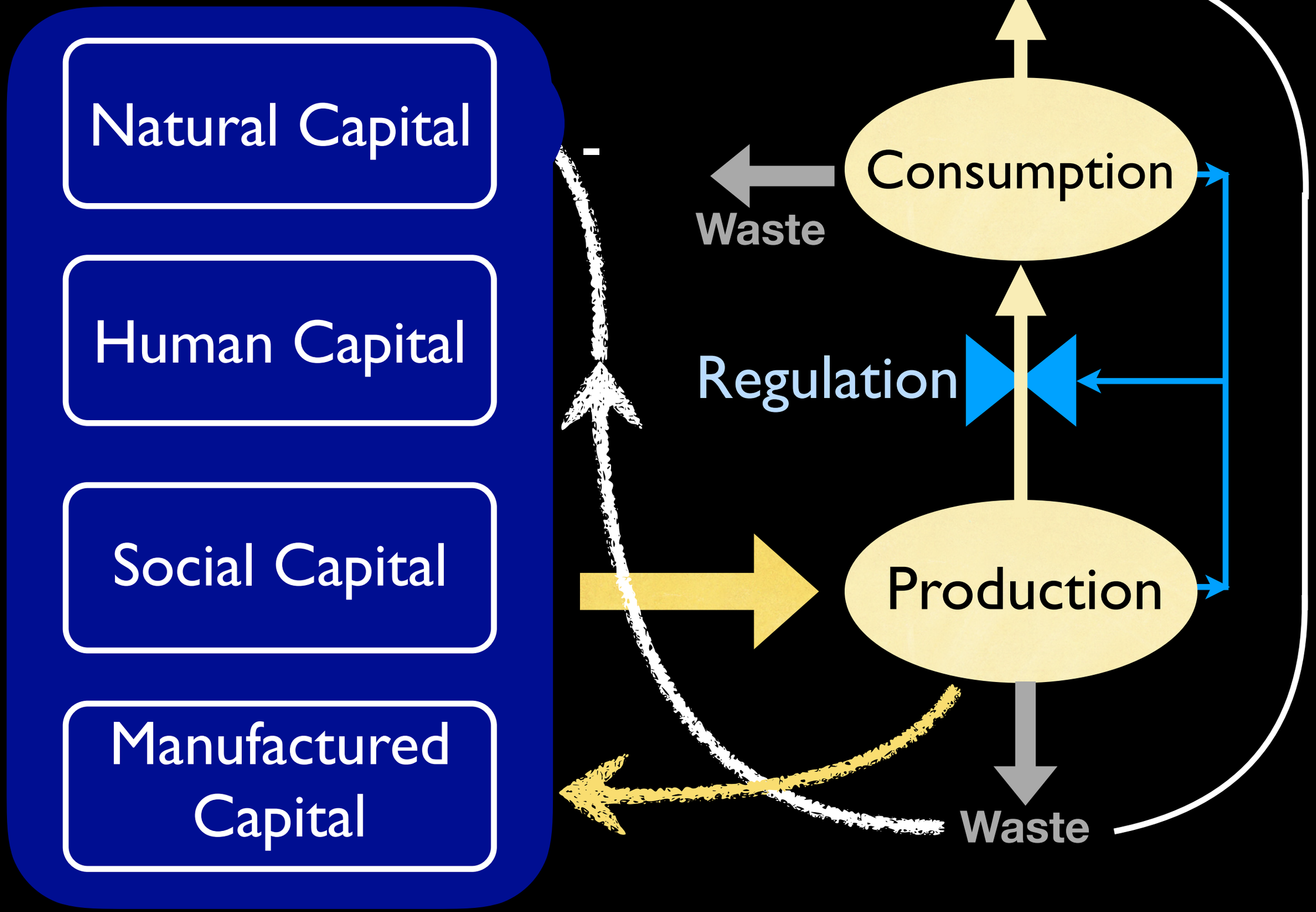
Entrepreneurship represents the input of

organisational and creative work

that marshals the other factors into productive harmony.

https://www.wedgetail.vc

Ekins et al.4 Capitals



These capitals become functional when combined to do

Work

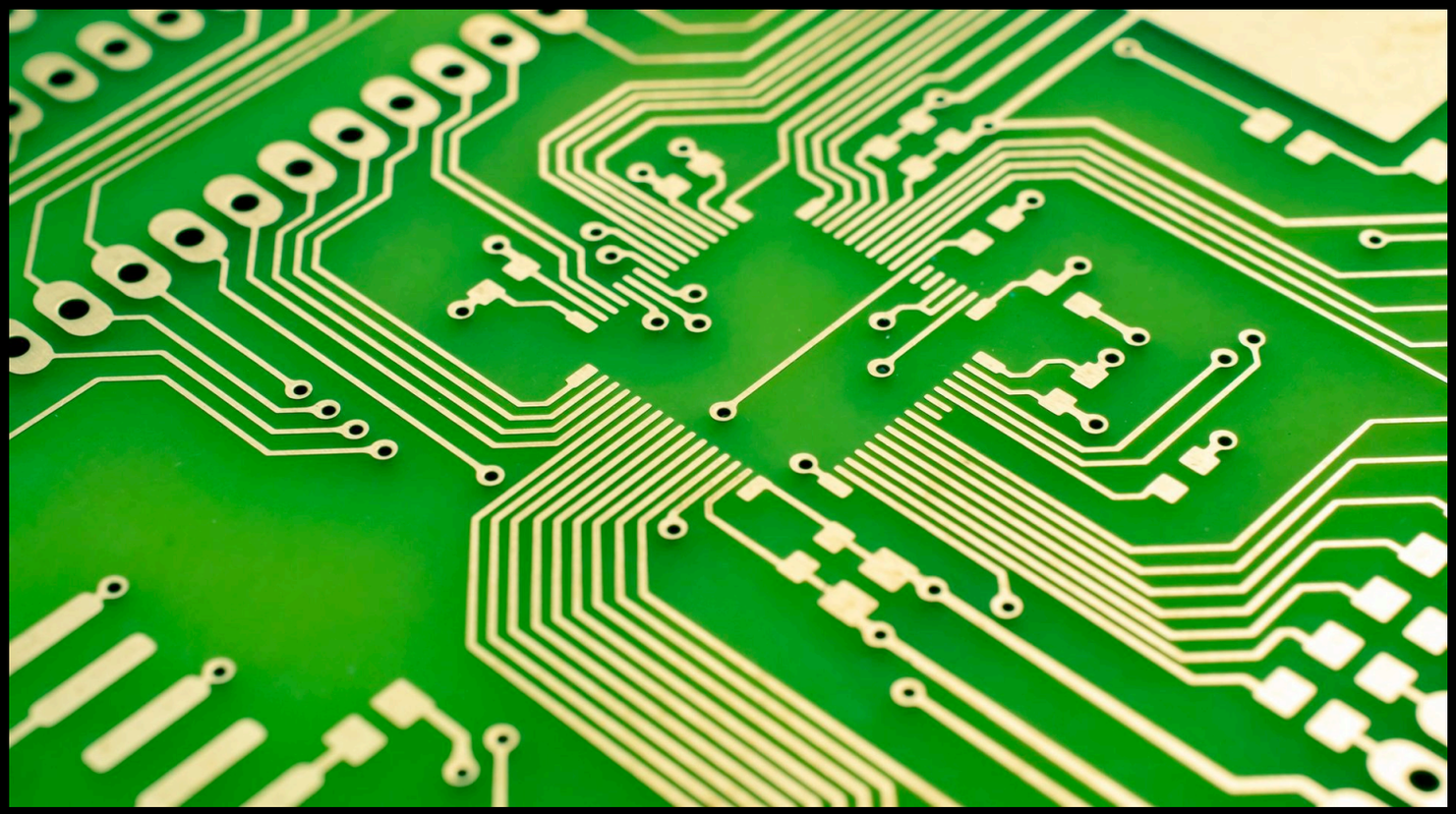
A pattern (information) at level *L+1* composed of patterns, each at level *L*

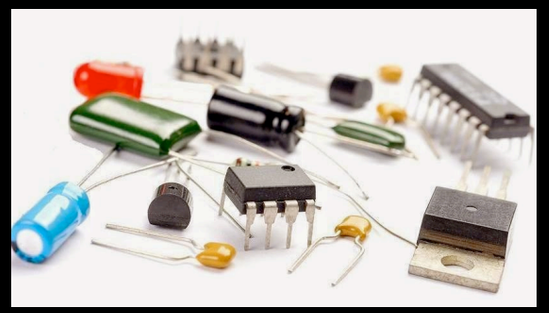
https://www.picturemosaics.com

Organisational work

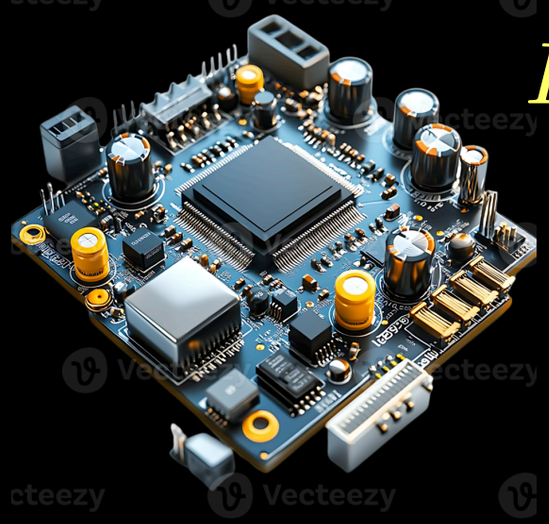
Organisational work is the investment of information at the assembly level of a system

making a pattern of patterns

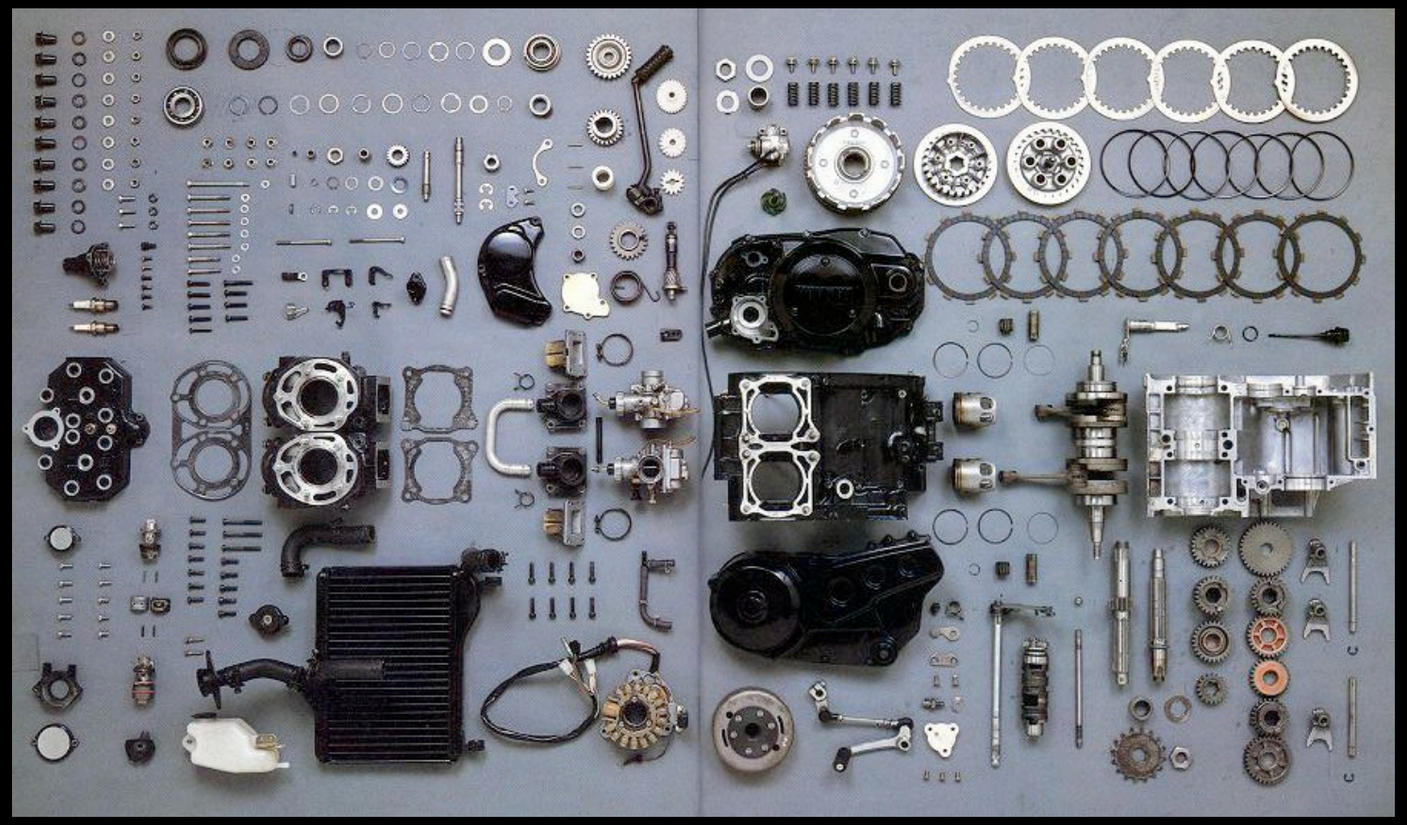




$L\mathcal{I}_p$



$L{+}1\mathcal{I}_p$

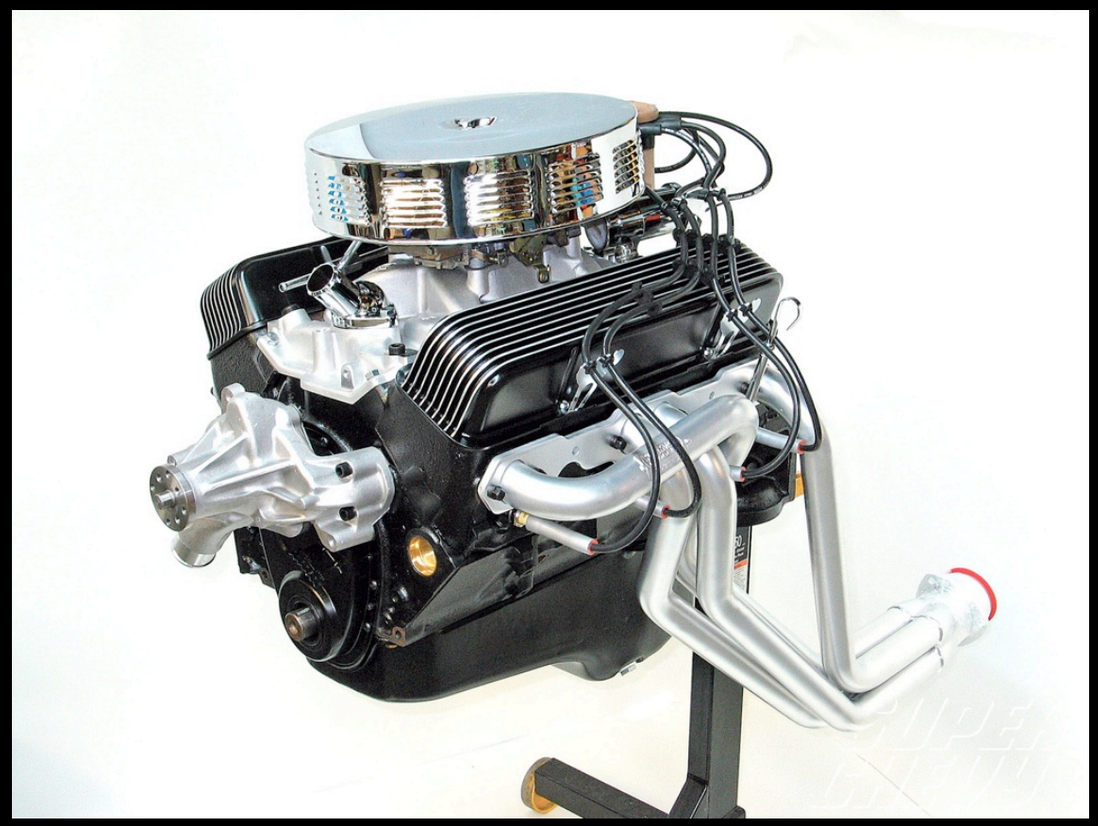


$^{L}\mathcal{I}_{p}$

Organisational work

Assemble elements in the right way to make a higher level ‘whole’.

$^{L+1}\mathcal{I}_{p}$



Organisational work

Putting the ingredients together to assemble something new

e.g. composing a piece of music

"all the right notes, but not necessarily in the right order"

Organisational work

Coordinating the actions of components to contribute to the function of the whole.

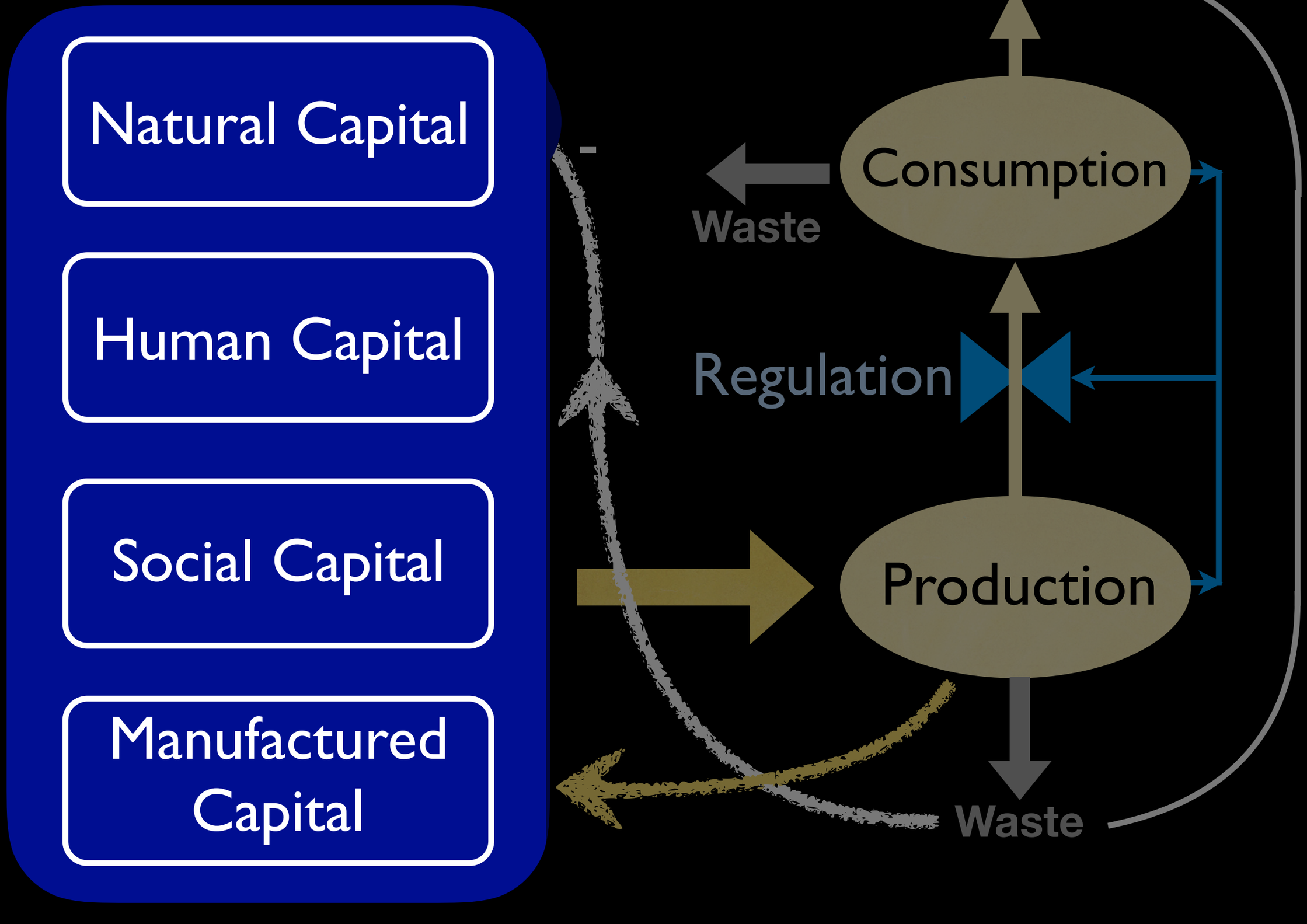
e.g. directing a surgical team in the operating theatre

Where is the organisational information in this case?

Information processing work

Thinking, planning, creating, evaluating, synthesising, sorting, eliminating, writing, communicating.

Ekins et al.4 Capitals



What determines capacity for work?

https://waterwheelreview.com/

The flow of Energy Constrained by a physical structure

Gravitational Potential Energy

Constrained Kinetic Energy

What determines capacity for work?

https://waterwheelreview.com/

The flow of Energy Constrained by a physical structure

Embodied Information

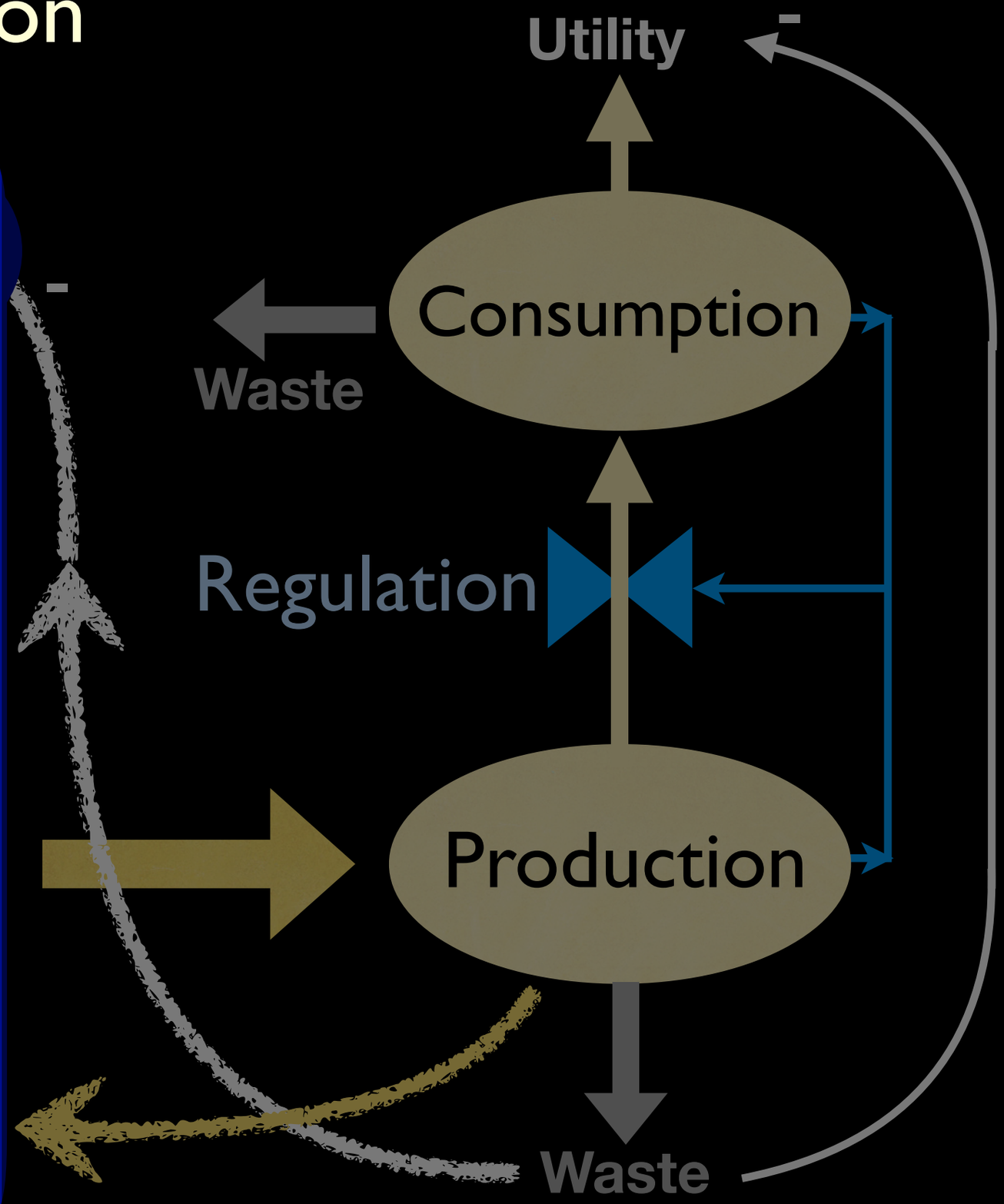
Factors of Production

Natural capacity for work

Human capacity for Work

Individual & Social

Manufactured Capital



Physical Work

Knowledge

Cognition

https://stockcake.com/i/artisan-weaving-textiles_687525_846265">Stockcake

ism.org/

schouxinpan.com

mossgielfarm.co.uk/

Every kind of ‘labour’ combines sources of informational constraint on the flow of energy to produce informed products.

ism.org/

schouxinpan.com

mossgielfarm.co.uk/

Combining physical coordination and mechanical constraint to produce an organised material outcome.

Economic growth has always been built from increasing productivity.

The history of productivity increase is one of accumulating functional information

Flint tool

1kb

Iron age tools

10kb

19th C. hand lathe

1Mb

21st C. digital CNC milling machine

1000Mb

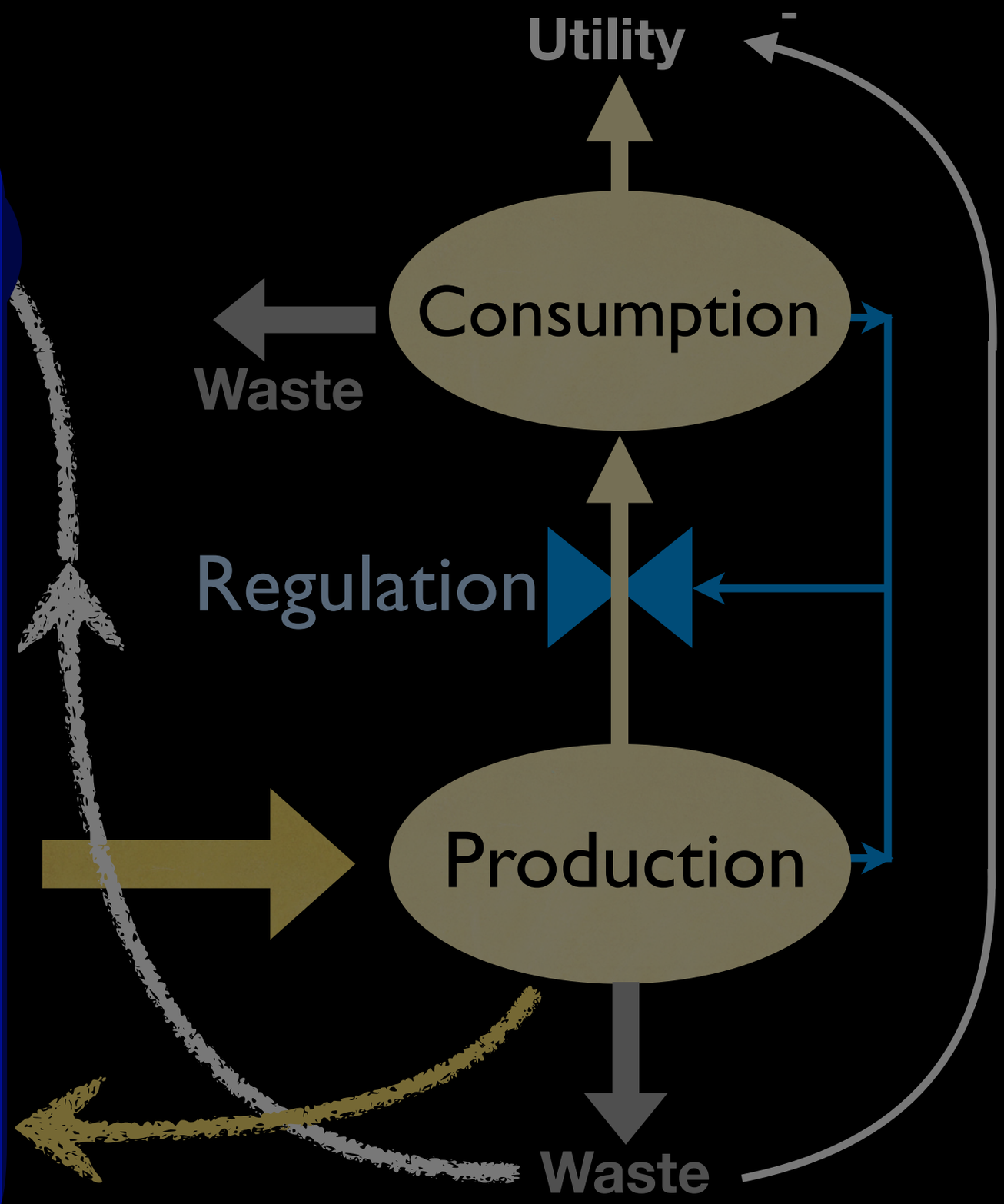
Physical Capitals

Flow of Energy

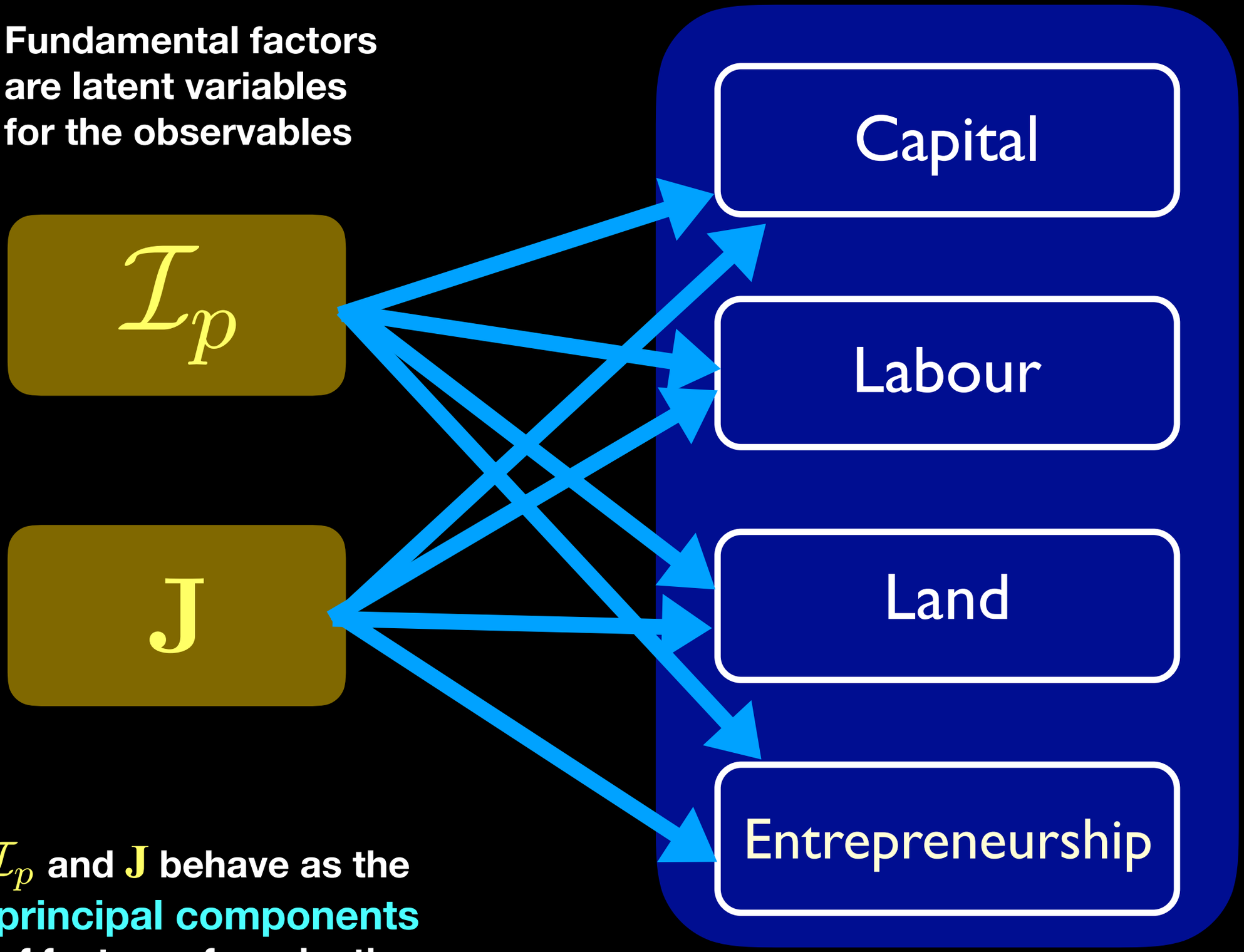
Information

Individual & Social

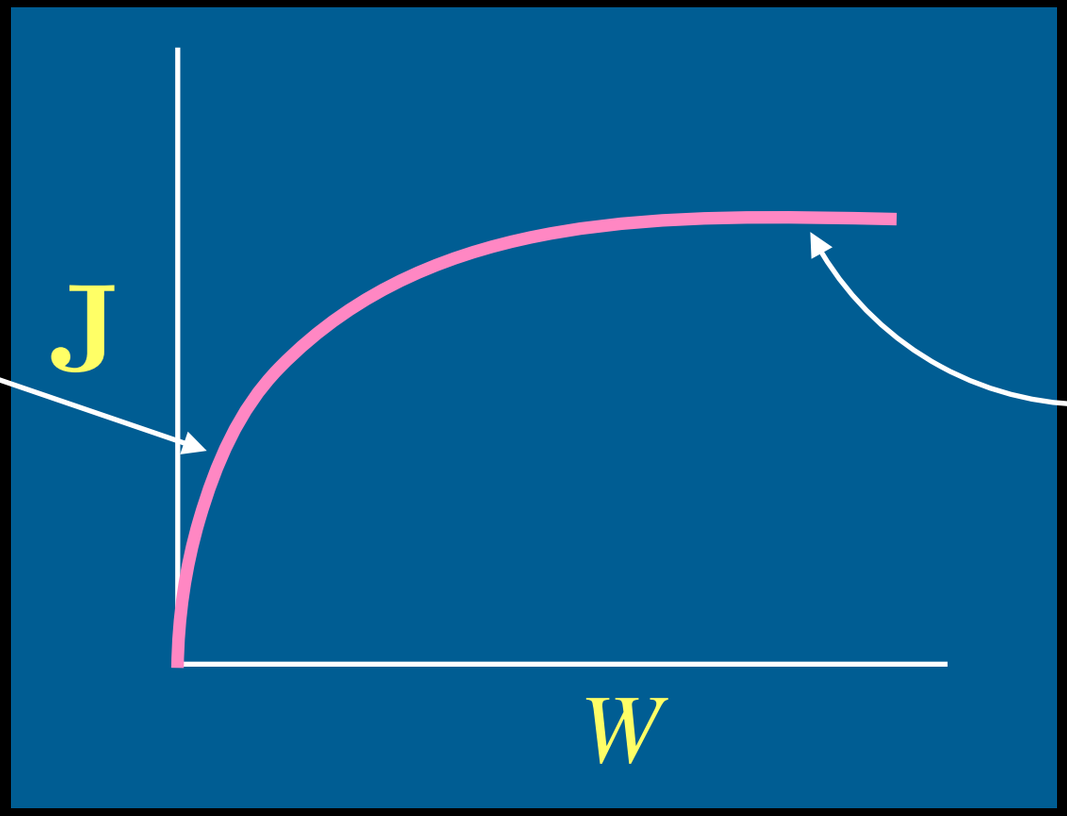
Manufactured Capital



Fundamental factors are latent variables for the observables

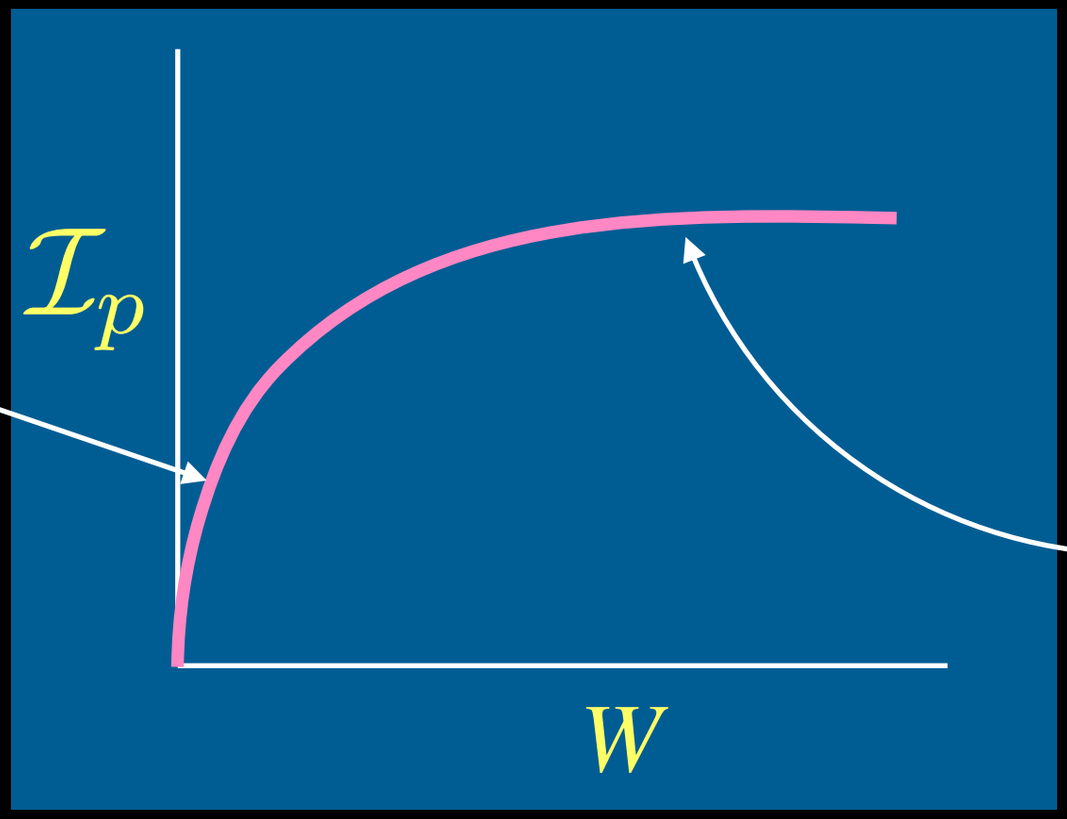


$\mathcal{I}_p$ **and** $\mathbf{J}$ **behave as the principal components of factors of production**



Laws of diminishing marginal returns.

$$\frac{\partial y}{\partial x} > 0 \ \forall x \qquad \frac{\partial^2 y}{\partial^2 x} < 0 \ \forall x$$

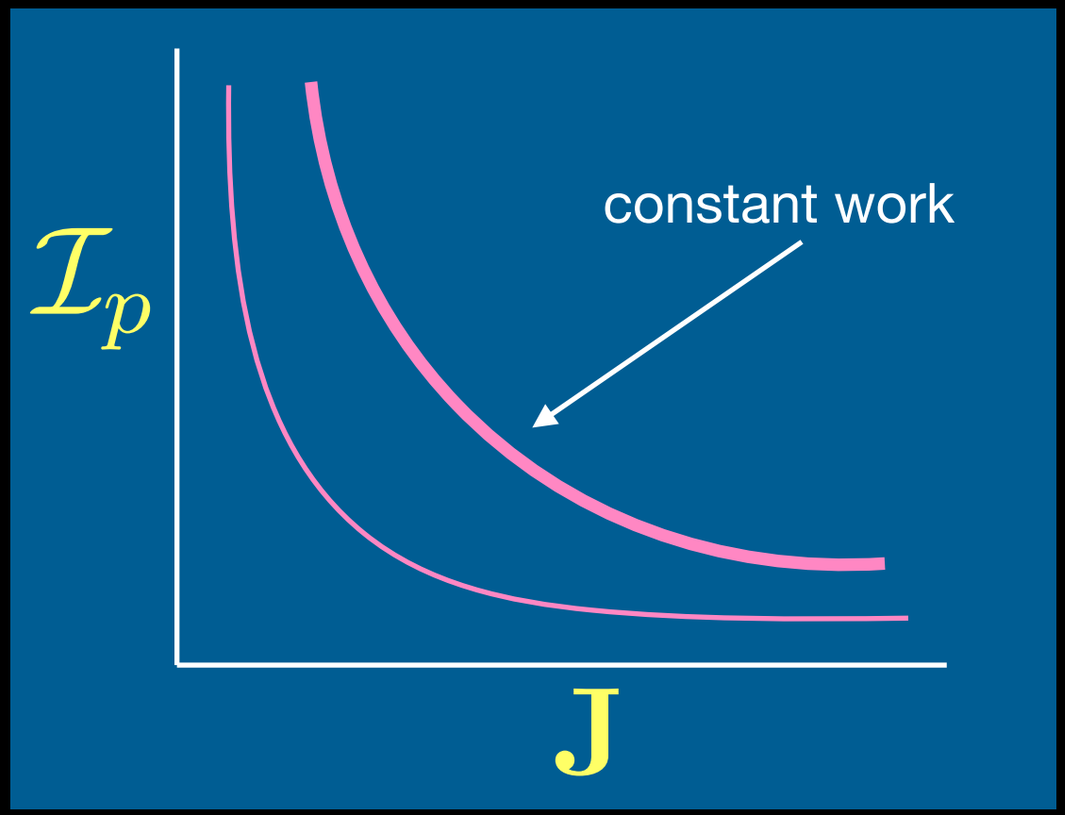


Nobody pays for energy - it is the work we intend the constrained flow of energy $\mathbf{J}$ to do that we value and pay for.

The more information $\mathcal{I}_p$ invested in a machine, the more effectively it can constrain $\mathbf{J}$.

The more effectively $\mathbf{J}$ is constrained, the more work we get from it.

If $\mathcal{I}_p$ and $\mathbf{J}$ are the two factors of production, then we can manipulate the balance between them through economic policy.



Production Function

The trade-off between $\mathbf{J}$ and $\mathcal{I}_p$

(note effect of concavity)

Information vs Energy flow

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Information vs Energy flow

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Biodiversity

Nutrient diversity

Human social diversity

All this diversity is embodied information

© LEK.com

Monoculture

High energy inputs

Low human input

Information vs Energy flow

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Ecosystem

Economy

$\mathcal{I}_p$

The common currency is physical information

Every technological revolution since the stone age has resulted from an increase of information processing capacity which led to an increase of organisation and energy flow rate.

Mastery of tools and fire

Embodied understanding of nature

From gathering to cultivating

Social organisation

Agricultural systems development

Metalwork and machines

Understanding mechanics

Mechanised warfare

Engines: constrained energy flow

Turning humans to machines

The Industrial Revolution

Understanding control logic

Electronics -> the computer

Organising human minds through computer systems

Information Technology - WWW

AI

Cybernetic world

That's all folks