

# Responsible Citizenship in a Technological Democracy

## Note 4: Systems

This is the first of a series of course notes discussing some simple, but fundamental concepts that will help you be a responsible citizen in a technological democracy. There will be something on the order of a dozen such concepts – not a large number. Each will try to make the concept only as complicated as necessary as you need to be a responsible citizen – and usually that’s not complicated at all!

The first such concept will be that of a “system”. As you’ll see, both for technical activity and for policy analysis, it’s critical to have the full “system context” on the table from the get-go.

**Concept:** A *system* is something made from a collection of simpler things – usually called components, parts, or subsystems. Each part has a function and the collection of parts have relations among them that let the assemblage accomplish some larger function.

Your car is a system made from components that include the engine, the brakes, the steering mechanism, and so on. There are relations such as which parts are connected to which other parts that accomplish the function of transporting you and your stuff from place to place

You will sometimes hear the phrase “system of systems” to describe the situation where the components of one system are themselves systems. Your car, in fact, is such a system of systems because, for example, the engine is a system whose components include the fuel injectors, the sparkplugs, etc.

The concept of a system is useful in designing things as well as in analyzing how an extant system works. For both of these objectives, some system designs are better than others. In particular

**Concept:** A crucial characteristic of a *good* system design is that you can understand how the whole works by knowing just *what* its components do and their *relationship* to each other, but not *how* they do what they do.

Merely chopping a big complex problem into pieces won’t necessarily make it easier to understand. Each of the pieces, and all of the interactions between them ought to be simpler to understand than the system as a whole. Indeed, the simpler they are the better!

As noted above, the concept of a system is useful in designing things as well as in analyzing how an extant system works. Let’s consider design first. When engineers design a complex device – say the next commercial airliner from Boeing – they will first describe its components (wings, engines, etc.) and how they interact at a fairly abstract level. Then separate design teams will be assigned to the separate components and, in parallel, the teams will consider alternative implementations for their component. Since something like a commercial airliner is very complex, it’s likely that this process of “system decomposition” and design will proceed through

many levels before concrete decisions will be made. But in the end, the idea is to find the best implementation of each component.

The notion that some implementations are better than others implies that we need more information than just what a component is to do. We also need to specify what makes one implementation better than another. In the context of a particular system design, is smaller better, is reliability important, is power consumption an important concern, what are the safety issues, what is an acceptable cost, and so on. The answers to these questions will depend upon the role that the component plays in the larger system.

**Concept:** To evaluate whether one implementation of a component of a system is better than another, you must evaluate the two in the context of the whole system in which they will be a part.

A refrigerator is a refrigerator, right? Well, yes, but the best refrigerator for an ocean liner and the best refrigerator for the space shuttle will be very different. The one for the ocean liner will be *big*, and its weight and power consumption won't matter much. Exactly the opposite is true for the one for the space shuttle. Moreover the "operating environment" in space is cold, so there may be some design options available to the designer of the shuttle refrigerator that aren't available to the designer of the ocean liner refrigerator. The point is that what makes one design of a component better than another comes from the context of the system within which it is used. There is no universal "best" for all contexts.

It's interesting that most natural objects are systems. Our bodies are systems with components such as the circulatory systems, the lungs, the liver, etc. Many of these are also a system, so our bodies are really an example of a system of systems. As with the artificial systems built by engineers, to understand the macroscopic operation of the body we only need to know what each subsystems *does*, not how it does it. Only when we want to know, for example, how a subsystem such as the heart works do we need to learn about its various chambers and valves.

## **Policy Relevance**

Many policy discussions boil down to the question "is A better than B?", where A and B are often either policies or technologies. Remember, when doing a systems analysis, you must *always* keep in mind the context of the larger system within which the component being analyzed is embedded! This is really important!

Burn this into your brain –

**Concept:** *There is no answer to the question "is A better than B" unless you know the larger context, the system, in which A or B will be used and how A or B will interact with the other components of that system!*

So, when evaluating either a policy or a technology, you must first ask yourself about the larger "systems context". What role does the policy or technology play in that system, and what other

components of that system might it interact with, and hence may be relevant to the current discussion?

For example, consider the many suggestions for using hydrogen as a transportation fuel. The usual rationale is that when hydrogen burns the result is pure water. No pollution. No carbon dioxide. That's true, but it's not the whole story. Hydrogen isn't something that you can pump out of the ground; it has to be *made*. A hydrogen-powered vehicle, then, is part of a larger system that includes at least the process of making hydrogen, transporting it to where it will be used, storing it on board the vehicle, and perhaps more. Whether using hydrogen as a transportation fuel is a good idea depends on whether all of these things *taken together* are a good idea.

Among the most complex of systems is our planet's ecology. The number of flora, fauna and inanimate substances such as air, water, and soil on the planet is immense, and their interactions and inter-dependencies are both rich and subtle – as is demonstrated by the unintended damage done by “invasive species”. Yet often these interactions and dependencies aren't considered by well-meaning advocates of various environmental policies. That's a recipe for making things worse!

As noted at the beginning, this is the first of a series of notes discussing some simple, but fundamental concepts that will help you be a responsible citizen in a technological democracy. It is the first because the first thing you should do when considering any public policy issue – when reading a newspaper article about electronic voting or the enrichment of uranium in Iran – is to be sure that the relevant system context is on the table. I think you'll be surprised how often it isn't!

### **Aside 1**

You may hear engineers talk about the “state” of a system. What they are talking about is what's going on at a moment in time. If your body is the system under discussion, for example, it's “state” includes your current heart rate, your current blood pressure, your current temperature, whether you are awake or asleep, and so on

It's the nature of any system that what happens next is a function of what's happening now plus an external stimulus. So it's convenient to talk about what's happening now as the “state” of the system, and what will happen next as its “next state”.

### **Aside 2**

You may also hear engineers use the phrase “levels of abstraction”. What they are talking about is exemplified by the earlier discussion of the system decomposition of an airliner design. One starts with a quite abstract description.

So, you want a plane to carry 200 passengers. OK, we'll need a fuselage about so long and so wide. We'll need wings to provide enough lift and engines to provide so much thrust. ...

Then each of these components will be described a little more concretely, but still pretty abstractly.

OK, if the wings are to provide so much lift, they will need to be so long, so wide and have a cross-sectional profile of thus and so ....

After many such levels of increasing specificity, things will finally become very concrete:

This wing strut must be 1/8<sup>th</sup> inch type X aluminum and must be attached to that cross brace with number 8 steel rivet ...

The purpose of these multi-levels of abstraction is partly just to keep intellectual control of the complexity of the design, but it's also the case that different kinds of analysis are appropriate at different levels of abstraction. To calculate the range of the new airliner, for example, only some abstract properties are needed – the weight of the plane, the drag on it, the fuel capacity, etc. What the wing struts are made of, or how they are fastened to the cross braces are irrelevant. On the other hand, if you want to know the safety of the wing in violent turbulence, the details of the design really matter!

As we said early in this note, a key to good technical design *and* to good policy analysis, is being sure that you have all the relevant “system context” on the table when doing that design or analysis!