

AIRLOCK

How humans turn interacting parts into coherent structure

Complex cognition in language, music and air traffic control



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Short project description — ecallegari@hi.is

In one sentence: AIRLOCK investigates *complex cognition*: how humans manage systems with many interacting parts, comparing language production, musical composition and air traffic control.

Choose your level of explanation

Click one of the options below to jump to the explanation most relevant to you.

I am neither a linguist nor a complexity scientist

I am a linguist

I am a complexity science researcher

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General Overview

What do speaking, composing music and directing air traffic have in common?

At first glance, very little. One belongs to everyday communication, one to artistic creation and one to a highly regulated, safety-critical profession. But all three involve a similar problem: many different elements and constraints have to be kept compatible as they are organized into a coherent structure that evolves over time.

This is what makes them complex. In a complex system, the parts do not simply sit next to one another; they interact. A change in one part can affect what is possible elsewhere. Several individually reasonable choices can combine badly. Local decisions can create larger patterns, constraints or conflicts that were not obvious at the start. The difficulty is therefore not only that there are many things to keep track of, but that those things affect one another in **non-linear** ways: small changes can have larger consequences, and choices that work individually can interact in unexpected or conflicting ways.

An **air traffic controller** has to organize many aircraft moving through limited airspace. The complexity does not come only from the number of aircraft, but from the fact that the relevant constraints vary: how far apart aircraft must be can depend on sector, altitude, aircraft type, speed, equipment, weather, route structure and phase of flight. A local decision that solves one spacing problem may therefore create a new conflict elsewhere in the traffic configuration.

A **composer** has to combine different instruments and musical lines into a coherent piece. The complexity does not come only from the number of parts, but from the fact that each part changes the conditions for the others. An instrument may fit in one register but disappear in another; a line may work on its own but clash when combined with a different timbre, rhythm or harmonic context.

And **every time we speak**, we have to find the words we need, arrange them into a grammatical sentence, decide what information should come first or receive emphasis, and turn all of that into fluent speech almost instantly.

AIRLOCK studies these three activities as examples of **complex human cognition**: how people make sense of, act within and control systems made up of many interacting parts. The project asks how humans make these systems manageable. What do experts attend to, and what do they ignore? How do they prevent conflicts before they arise? How do they simplify a situation without losing control of it? How do they make local decisions that still add up to a coherent larger structure?

The reason for comparing air traffic control, musical composition, and language production is that they are deliberately different. Air traffic control is procedural, safety-critical, and time-pressured. Musical composition is creative, aesthetic, and open-ended. Language production is ordinary and everyday, but extraordinarily fast and complex. If similar strategies appear across such different domains, they may reveal something general about how humans manage complexity.

AIRLOCK therefore uses these domains as windows onto a broader question: how do humans turn many interacting possibilities into a coherent outcome?



Figure 1: Studying complexity-reducing strategies at the Reykjavík Air Traffic Control Center

Are you a composer?

I am currently interviewing composers for the musical-composition part of AIRLOCK and would love to talk to you. This would be a short, informal online conversation about how you approach the composition process: how you combine instruments, voices, textures, constraints and musical ideas into a coherent whole.

I would also be very interested in hearing from researchers working on related questions, for example cognition in composition, cognitive modelling of air traffic control, expertise in complex dynamic systems, or how people manage complexity in real-world domains.

Interested in the project, or see a connection to your own work? Drop me a line at:

ecallegari@hi.is

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I am a Linguist

One of the most remarkable facts about language is **how effortlessly speakers coordinate an enormous number of processes in a very short time frame.**

To produce a single sentence, a speaker must select lexical items together with their syntactic and morphological properties, organize them into hierarchical relations and establish dependencies such as agreement, binding and movement. At the same time, the sentence must be linearized, information must be packaged as topic, focus, background or contrast, and, in speech, the resulting structure must be mapped onto phonological and articulatory execution. **These processes interact non-linearly and constrain one another,**

and must be managed under time pressure and limited memory.

AIRLOCK starts from the hypothesis that some properties of syntactic organization may be shaped by pressures of real-time *complexity management*. Producing a sentence requires many partially interdependent processes to remain compatible with one another as the structure unfolds. The hypothesis is that some properties of syntax may exist precisely because they make this coordination problem manageable. If this is right, then some of the pressures shaping syntax may also be visible in other domains where humans manage complex, interacting systems.

To investigate this, **I look beyond language to two comparison domains: air traffic control and musical composition.** In air traffic control, controllers must monitor many moving aircraft and maintain safe separation among them under strict time pressure, while also tracking constraints that vary across aircraft, routes, sectors, altitudes, weather conditions, equipment types and phases of flight. In musical composition, composers must combine instruments with very different properties and constraints: range, timbre, volume, register, texture. They have to decide which instruments can coexist, which should dominate or recede, how potential clashes can be avoided or exploited, and how many local choices can add up to a coherent musical structure. These domains differ sharply: one is institutionalized, procedural and safety-critical; the other is creative and open-ended. Yet both involve the management of multiple interacting elements into a stable, coherent output.

By studying how experts in these domains manage complexity, prioritize information, avoid or resolve conflicts, and distribute attention across competing demands, my goal is to identify general strategies of complexity management that may also be relevant to language. The project asks whether the cognitive strategies humans use to manage complex, non-linear interactions in other domains can help us formulate a more dynamic theory of syntactic organization, using the Left Periphery as an empirical case.

The Left Periphery is a region of the clause where syntactic complexity is especially visible: it is where many different processes converge, including topicalization, focus movement, wh-movement, modifier fronting, complementizer selection, V2 fronting. For this reason, it offers a particularly useful test case for asking how multiple interacting processes are kept compatible as a sentence unfolds.

Interested in the project, have relevant data, or see a connection to your own work? I would be very happy to hear from you.

Contact: ecallegari@hi.is

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I am a Complexity Science Researcher

AIRLOCK investigates what I call *complex cognition*: **how humans make sense of, act within and exert control over complex systems**, and hence systems composed of multiple interacting components whose relations are non-linear and which can give rise to emergent effects. As a result, the global behavior of the system cannot easily be understood by considering each component in isolation.

This raises a central question: how do humans cope cognitively with systems whose behavior is high-dimensional, dynamic and only partially predictable? In many real-world domains, people cannot compute or represent the full global state of a system at every moment. They must instead reduce complexity, identify relevant structure, prioritize some interactions over others and keep the system within a manageable range of stability.

AIRLOCK approaches this question **by comparing three domains that are intentionally very different, but structurally comparable in one respect: all require humans to manage complex, interacting systems as they unfold in time.** The domains are air traffic control, musical composition and

language production.

In **air traffic control**, controllers manage aircraft whose trajectories interact under changing operational constraints: separation minima, altitude, speed, sector boundaries, weather, equipment, route structure, traffic density and handover procedures. In **musical composition**, composers manage interacting voices, instruments, registers, timbres, rhythmic layers, harmonic or melodic materials, textures and larger formal developments. In **language production**, speakers have to find the words they need, arrange them into a grammatical sentence, decide what information should come first or receive emphasis, and turn all of that into fluent speech almost instantly, while all these choices constrain one another as the sentence unfolds.

The project asks whether these domains rely on comparable strategies for reducing interactional complexity, and whether they exhibit similar biases in how complex configurations are made tractable. These strategies may include locality, decomposition into manageable subdomains, limited lookahead, reusable templates, early ordering decisions, simplification under load, conflict avoidance and the redistribution of complexity across time.

The broader aim is to identify general principles of human complexity management: how people reduce a high-dimensional problem to a manageable working configuration, stabilize interacting components, prevent local conflicts from propagating through the system and produce globally coherent outcomes without computing or representing the full global state at every moment.

Do you work on the study or modelling of complex dynamic systems?

I would be especially interested in hearing from researchers working on cognitive modelling of how people manage complexity in real-world domains, such as air traffic control.

Interested in the project, or see a possible conceptual or modelling connection? I would be very happy to hear from you.

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