Task Analysis for Teaching Cumulative Learners

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Outline

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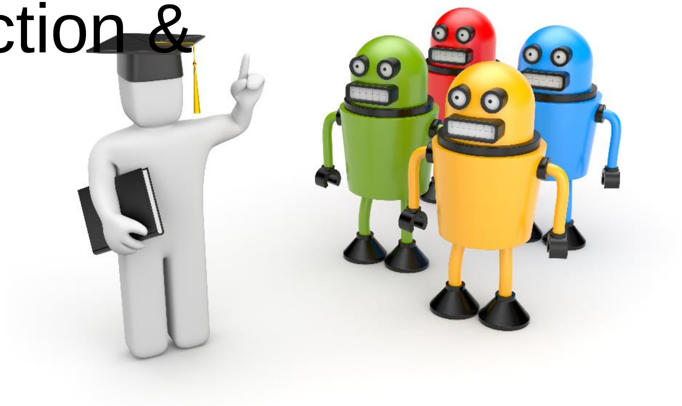
- Curriculum Construction
- Conclusion



Introduction

- **Scope:** using *existing knowledge* to *teach cumulative learners*.

- Air Traffic Control is a complex domain, which requires cumulative learning.
- The more complex the task, the more can be gained from knowledge transfer / teaching.
- Expert domain knowledge and teaching materials are often available *for humans.*

Air Traffic Control

- Safety-critical complex workflow
  - Current human implementation is “proven”
- Before full-automation is achieved, AI must work with human ATCOs.
- Automation must be introduced in a trustworthy and gradual manner that can be understood.
- Arrival Control: ensure optimal flow of aircraft arrivals.

Cumulative Learning

- Always on (lifelong learning)
- Continuous (online/incremental learning)
- New knowledge integrates and builds on with old knowledge (transfer learning)
  - Without catastrophic interference
  - Ideally enabling few-shot learning
  - Defeasible
- Acquires ability to perform a wide range of tasks over time (multitask learning)

Curriculum Construction

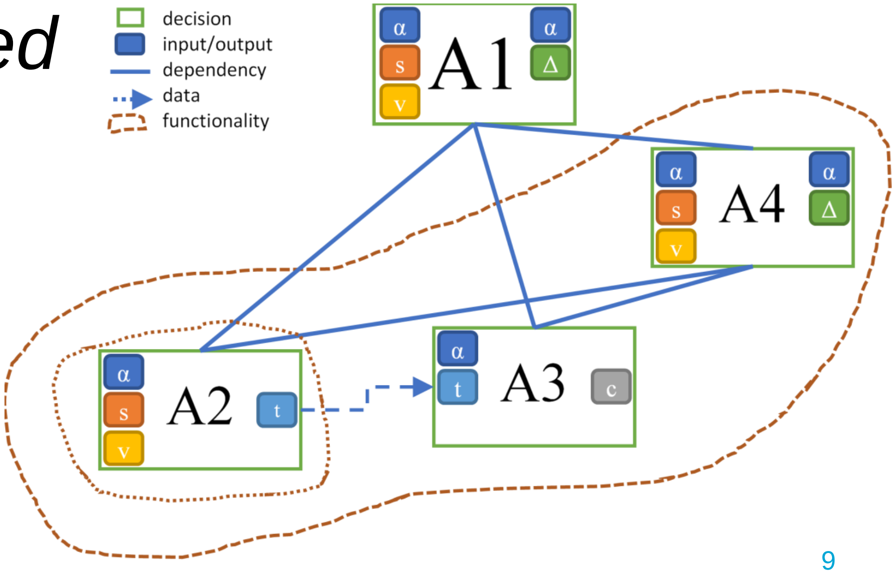
- Because new knowledge builds on old, the order in which things are learned matters.
- We want to construct a high-level curriculum that specifies topics of “lessons” and the order in which to teach them.
  - Low-level teaching depends on (a) the learning system, (b) available training resources and (c) the nature of the task.
  - Design phase in ADDIE
- Vygotsky’s zone of proximal development
  - Shaping / curriculum learning
  - Scaffolding
  - Part-task training

ADDIE model of instructional design

- *Analysis of the learner*
- **Design of the lesson plan or curriculum**
  - Involves analysis of the task / subject matter
- Development or assembly of the actual training materials
- Implementation of the instruction with the learner (i.e. the actual teaching/training/learning)
- Evaluation of learning outcomes

Task Decomposition

- **(sub)task-based / action-based**
- **feature-based / situation-based**
- *functionality-based*



Expert Knowledge

- Creating a teaching curriculum
  - Expert knowledge of:
    - **Task domain**
    - *Learning system*
    - *Teaching*

Requirements Engineering

- Step 1: produce one or more “scenarios” / “user stories” / “use cases”
- Interviewer elicits “actions” or “subtasks” that are involved in the task
  - “action” is very broadly defined
- Actions may consist of lower-level actions or otherwise depend on each other
- Create dependency graph

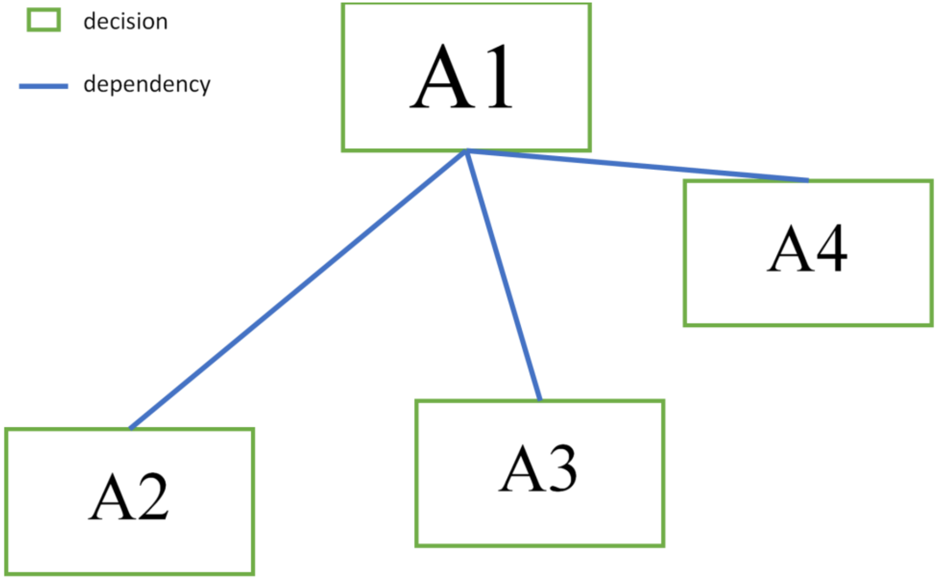
Interventions

- Action should be decomposed further
- Expert doesn’t know how to do action
- Composite action not fully described
- Child action A does not *directly* contribute to parent C

Scenario

- The Cumulative Learner (CL) needs to maintain a minimal separation time between landings (A1). First, the CL must predict the time at which each aircraft is expected to arrive at each runway (A2). Based on this information, the CL needs to detect if the arrival times of any two aircraft conflict (A3). Detected conflicts must then be resolved by telling an aircraft to speed up or slow down (A4).

Dependency Graph



Task Analysis

- **Input**
  - What things are taken into account?
  - What are the possible and simplest values?
- **Output**
  - E.g. “a message to pilot X to move up/down by Y amount at time Z” to “preparation/ prediction of the information for another action”
- **Method**
  - Straightforward series of steps/calculations or vague descriptions of intuitive processes
- **Evaluation**
  - What variables are being optimized?
  - What is their relative importance?

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Task Description

Scenario S1: Separation maintenance

The Cumulative Learner (CL) is presented with IDs, velocities, and distances of a fixed number of aircraft and needs to maintain a minimal separation time between landings (A1). First, the CL must predict the time at which each aircraft is expected to arrive at each runway (A2). Based on this information, the CL needs to detect if the arrival times of any two aircraft conflict (A3). Detected conflicts must then be resolved by telling an aircraft to speed up or slow down (by ±10% in our simplification) (A4).

Action A1: Separation maintenance

See Scenario S1.

Input: IDs α $\{0, 1, \ldots\}$, velocities v in m/s [1–400] and distances s in m [0–4,000,000] of a fixed number of aircraft

Output: ID + speed up/slow down 10% command, or nothing

Method: predict landing times (A2), detect conflicts (A3), resolve conflicts (A4)

Evaluation: +10 per landed aircraft, -1000 per conflict

Action A2: Arrival time prediction

Predict the time at which aircraft A will arrive at the runway.

Input: aircraft info for A (ID, velocity and distance)

Output: time t in s [0–10,000]

Method: $\frac{distance}{velocity}$

Evaluation: $\left\| t_{\text{predicted}} - t_{\text{actual}} \right\|_2$

Action A3: Conflict detection

Predict whether two aircraft A and B will have conflicting landing times.

Input: estimated landing times t

Output: conflict c yes/no

Method: $\|t_A - t_B\|_1 <$ threshold

Evaluation: $\|t_A - t_B\|_1 <$ threshold

Action A4: Conflict resolution

Resolve conflict between aircraft B and C.

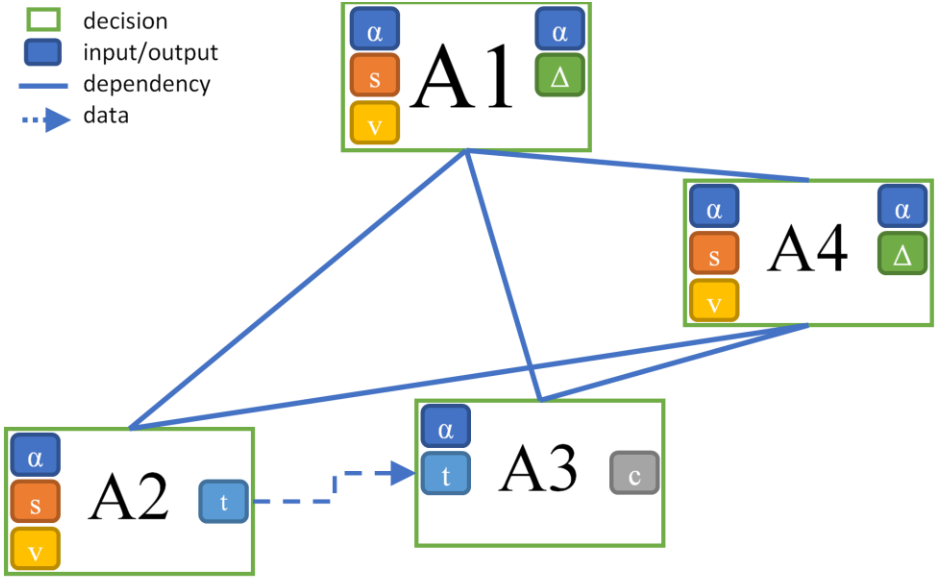
Input: ID, velocity, distance and arrival time of aircraft A, B, C, D, where A is directly before B, and D directly after C

Output: ID of B or C + speed up/slow down Δ 10% command, or nothing

Method: See if the conflict can be mitigated by speeding up B, without introducing conflict with A. If not, slow down C and invoke A4 for C and D if this creates a conflict.

Evaluation: $c_{\text{after}} - c_{\text{before}}$ (where global conflict cost c is the sum of all local conflict costs for aircraft pairs)

Task Graph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input/output
dependency
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A1
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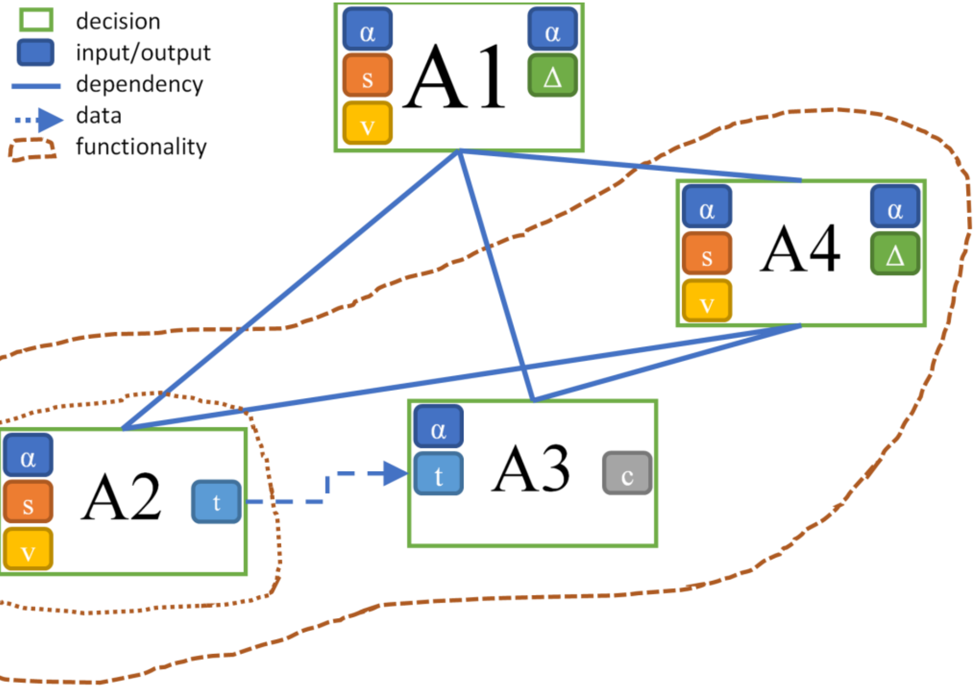
Task Graph



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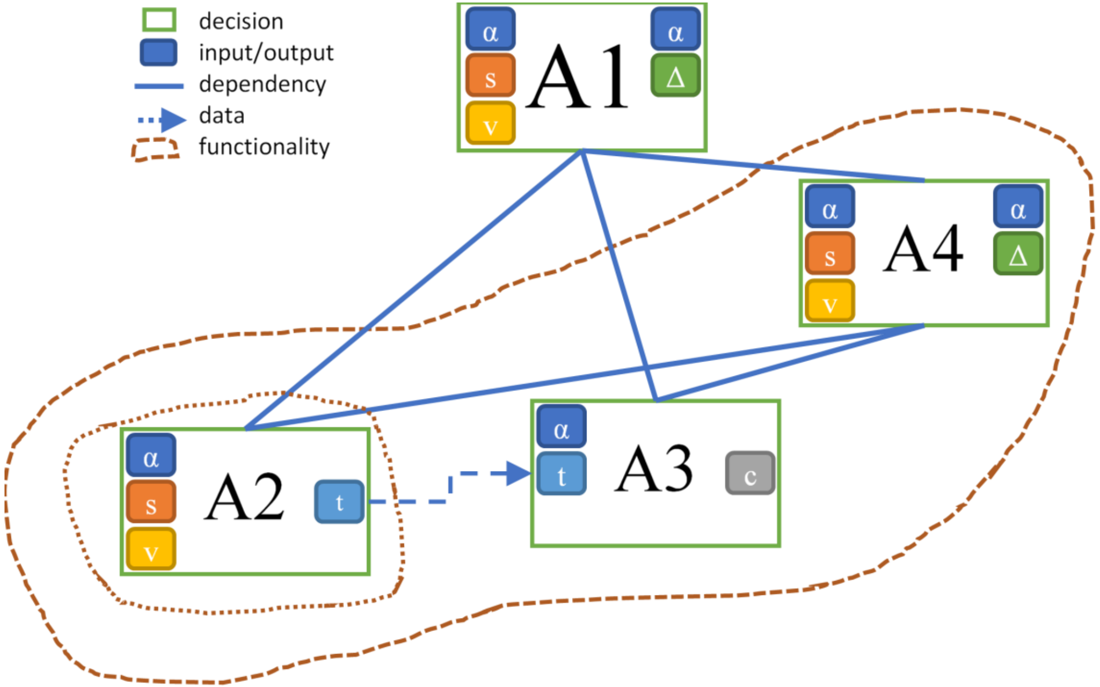
Curriculum Construction

- Needs-based selection of low-level functionality chunk
- Within chunk: bottom-up, left-to-right
- Use feature-based decomposition to simplify

Curriculum Construction



A2 → A3 → A4 → A1

Conclusion

- *Expert-based task analysis* to inform *design of teaching curricula* for *cumulative learners*
- Based on theories from functional requirements analysis, knowledge engineering, instructional design and pedagogy.
- AGI will be able to learn cumulatively, and be tasked with taking over work of human experts (who will have expertise).

Future Work

- Compare knowledge elicitation and task analysis methods with reasonable alternatives
- Use additional data sources
- Theory for constructing teaching curricula based on task analysis, but also characteristics of the learning system and available training resources
- Evaluation of constructed teaching curricula

Thank you!

- Thanks for your attention!

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