AI in education

Intelligent tutoring systems

March 8th 2019

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Outline

I

Context & history

II

Approach

III

Case study “counterpoint”

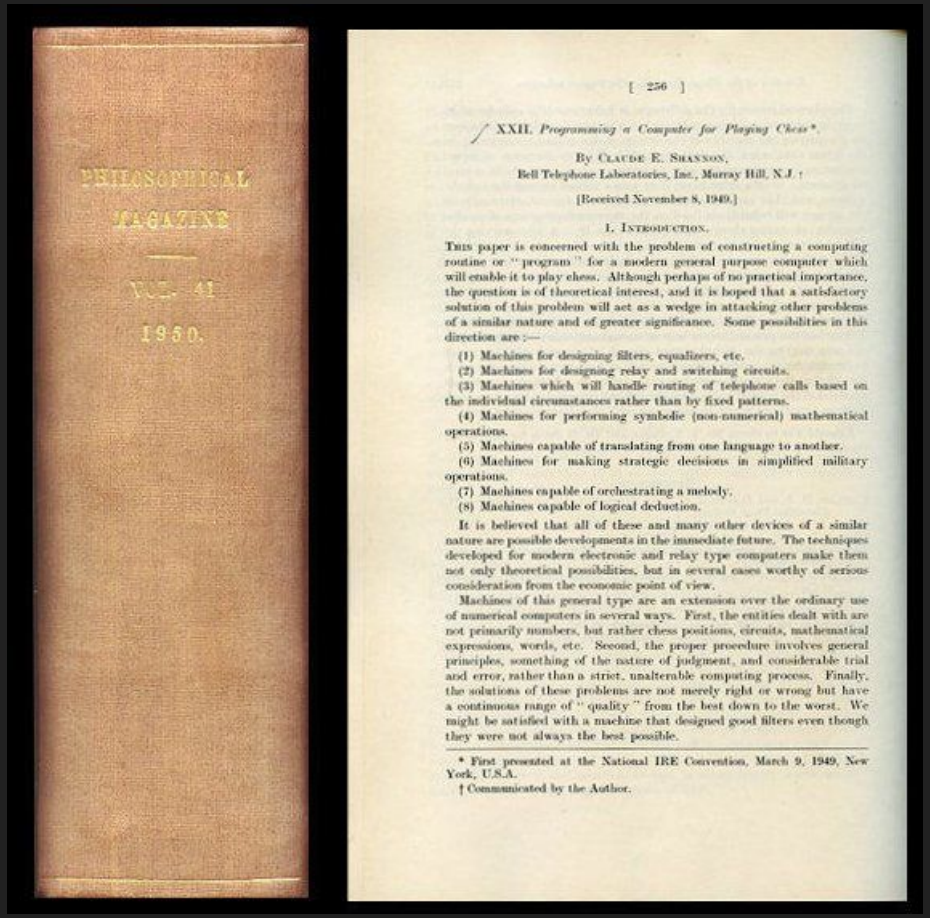
IV

Conclusions

PART I: Context & history

History of AI:
when did it start?

[The Analytical Engine] might act upon other things besides *number*, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine...Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, **the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.**



PHILOSOPHICAL MAGAZINE

VOL. 41

1950.

[256]

XXII. *Programming a Computer for Playing Chess**.

By Claude E. Shannon,
Bell Telephone Laboratories, Inc., Murray Hill, N.J. †

[Received November 8, 1949.]

1. Introduction.

This paper is concerned with the problem of constructing a computing routine or "program" for a modern general purpose computer which will enable it to play chess. Although perhaps of no practical importance, the question is of theoretical interest, and it is hoped that a satisfactory solution of this problem will act as a wedge in attacking other problems of a similar nature and of greater significance. Some possibilities in this direction are :—

(1) Machines for designing filters, equalizers, etc.
(2) Machines for designing relay and switching circuits.
(3) Machines which will handle routing of telephone calls based on the individual circumstances rather than by fixed patterns.
(4) Machines for performing symbolic (non-numerical) mathematical operations.
(5) Machines capable of translating from one language to another.
(6) Machines for making strategic decisions in simplified military operations.
(7) Machines capable of orchestrating a melody.
(8) Machines capable of logical deduction.

It is believed that all of these and many other devices of a similar nature are possible developments in the immediate future. The techniques developed for modern electronic and relay type computers make them not only theoretical possibilities, but in several cases worthy of serious consideration from the economic point of view.

Machines of this general type are an extension over the ordinary use of numerical computers in several ways. First, the entities dealt with are not primarily numbers, but rather chess positions, circuits, mathematical expressions, words, etc. Second, the proper procedure involves general principles, something of the nature of judgment, and considerable trial and error, rather than a strict, unalterable computing process. Finally, the solutions of these problems are not merely right or wrong but have a continuous range of "quality" from the best down to the worst. We might be satisfied with a machine that designed good filters even though they were not always the best possible.

* First presented at the National IRE Convention, March 9, 1949, New York, U.S.A.

† Communicated by the Author.

Claude E. Shannon, 1950, “Programming a Computer for Playing Chess”

First chatbot?

```
  Welcome to
                 EEEEEE  LL      IIII  ZZZZZZZ   AAAAA
                 EE      LL       II       ZZ   AA   AA
                 EEEEE   LL       II     ZZZ    AAAAAAA
                 EE      LL       II    ZZ      AA   AA
                 EEEEEE  LLLLLL  IIII  ZZZZZZZ  AA   AA

  Eliza is a mock Rogerian psychotherapist.
  The original program was described by Joseph Weizenbaum in 1966.
  This implementation by Norbert Landsteiner 2005.


ELIZA: Is something troubling you ?
YOU:   Men are all alike.
ELIZA: What is the connection, do you suppose ?
YOU:   They're always bugging us about something or other.
ELIZA: Can you think of a specific example ?
YOU:   Well, my boyfriend made me come here.
ELIZA: Is it important to you that your boyfriend made you come here ?
YOU:   He says I'm depressed much of the time.
ELIZA: I am sorry to hear that you are depressed.
YOU:   It's true. I am unhappy.
ELIZA: Can you explain what made you unhappy ?
YOU:
```

what are advantages and drawbacks of symbolic techniques like these?

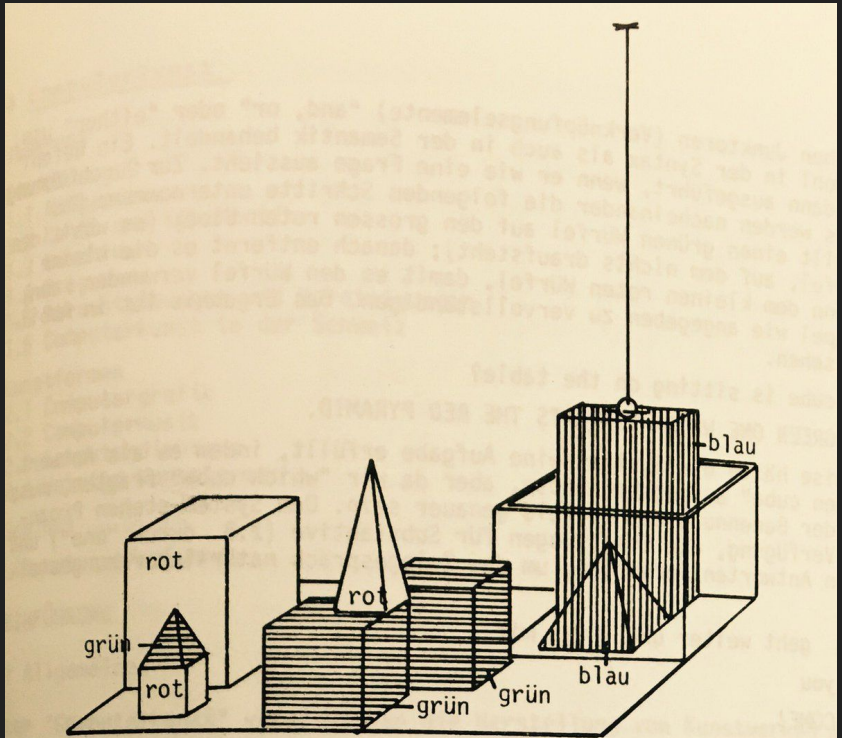


Abbildung 3: "Find a block which is taller than the one you are holding and put it into the box".

SHRDLU

Berkeley Logo

File Edit Logo Font

```
? repeat 4 [fd 90 lt 90]
? setpc 0
? repeat 4 [fd 90 lt 90]
? setpc 10
? repeat 4 [fd 90 rt 90]
?
```

AI and education: a long history

LOGO was conceived as a learning environment, based on the **constructivist** theory of Jean Piaget, that considers learning as a process in which learners *create knowledge* in their minds as they *interact* with things and people in the world around them.

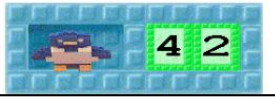
[Seymour Papert & Marvin Minsky]

AI and education

ToonTalk

programming as a video game

Minecraft

message array vector	box 
comparison test	set of scales 
process spawning	loaded truck 
process termination	bomb 
constants	numbers, text, pictures, etc. 
channel transmit capability message sending	bird 
channel receive capability message receiving	nest 
persistent storage file	notebook 

New Scientist

TECHNOLOGY NEWS 24 July 2013

Kindergarten coders can program before they can read

Going back to school to meet the 4-year-olds who are learning to program computers thanks to a new graphics-based coding language

Why now?

First: Education is at an inflection point

- Globalisation & innovation are changing the landscape of education
  - more awareness and higher mobility among students;
  - cultural diversity
  - transition from labour ⇒ knowledge ⇒ creative & networking society.

- UNESCO expects the global number students in Higher Education to rise to 250M from 150M today! To keep up with this demand, we should build 4 universities of 30k students / week

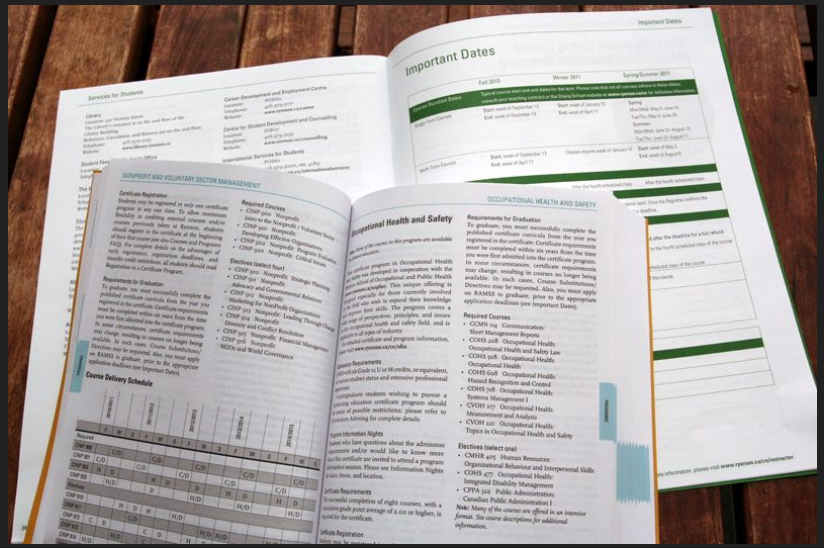
- Our methods of teaching are outdated! A lot is known, but the wheel is reinvented all the time. (E.g. Rovio)

Second: Maybe the time is right?

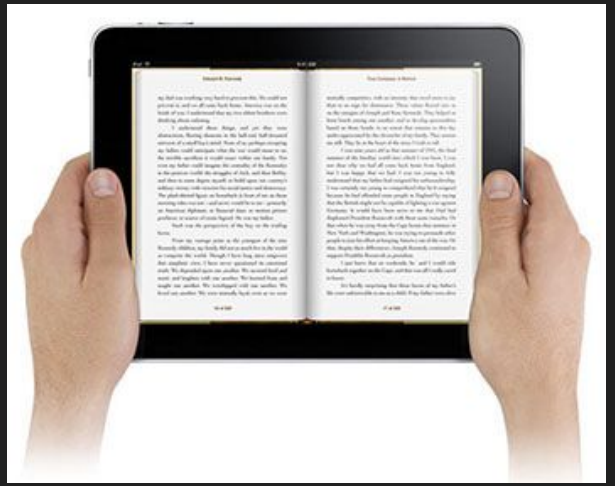
- **Sociological evolutions**
  - First generations of “digital natives”: participative culture
  - Techno-utopian age, political inertia

- **Technological** nexus of forces: start-up mania
  - Cloud computing’s age of scale
  - Social media
  - Mobile ubiquitous computing
  - Smart machines (AI)

Technology only matters when it reinvents the methods of teaching.



vs.



Gamification

Well-ordered problems

Sequence of challenges = level design. "Early problems set the player up for later success" ⇒ scaffolding!!

Pleasantly frustrating

ZPD or "regime of competence": create frustration that is not stressing, but creates flow. Make sure that they "know they will get the pleasure": the player feels confident (s)he can make it.

Cycles of expertise

Give problem where routine knowledge doesn't work anymore; this way they have to rethink their knowledge and "open up the black box". Then practice till it becomes routine (and thus, boring) and start a new cycle

Sand boxes

Give learners an environment where they have the opportunity to be in a safe space, but feel like in a dangerous space, to encourage exporation & taking risks

How can Artificial Intelligence help?

Technology Enhanced Learning, Computer Assisted Learning, Intelligent Tutoring Systems, AI & education, Adaptive Learning, Adaptive & Intelligent Educational Systems, ...

Many different technologies:

- Recommender Systems
- Expert systems
- Natural Language Processing
- Data mining
- Agent-based modelling
- Reinforcement learning
- Simulation
- “Gamification”

For many different tasks:

- Exploring content
- Automated assessment / grading
- Tutoring
- Personalizing content
- Usage & learning patterns

Who thinks

teaching = “transfer” of knowledge?

Who thinks it works like this?

I show, you read, done?

Challenges of intelligent tutoring systems

- How do we **keep students motivated**?
  - drop-outs
  - hard to stay focused on online content
- How to **guide students** through their curriculum?
- How do we know **what a student has learnt**?
- How to **represent domain knowledge** to make it intelligent & actionable?

Part I: Context & history

Part II: Approach

How to keep students motivated?

Two big “schools of thought”:

- **Behaviourism**: based on external rewards (“reinforcement learning”), ignoring emotions, interests, … Effective for small tasks, but leads to: detachment, depression,

- **Intrinsic motivation** theories focus on the question on how to make learning enjoyable and thus effective for the learner *and* teacher.

Theory of “flow”

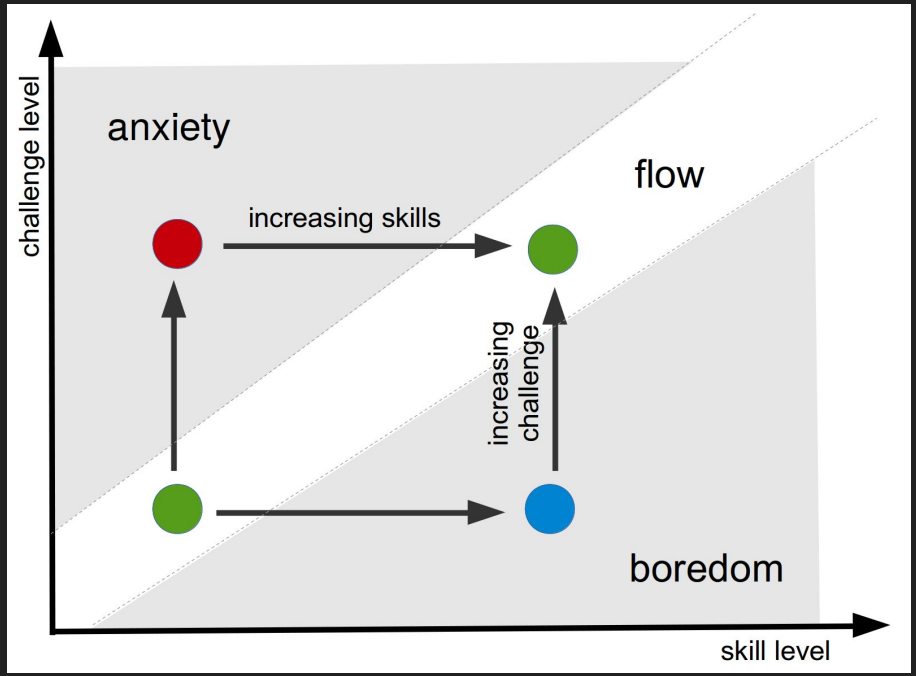
- Flow describes the situation in which people reach an optimal experience of **extreme focus of psychic energy**, high achievement, feeling of creativity, rapid learning and happiness.

- In this setting, no external reward/punishment system exists and is even counterproductive when given.

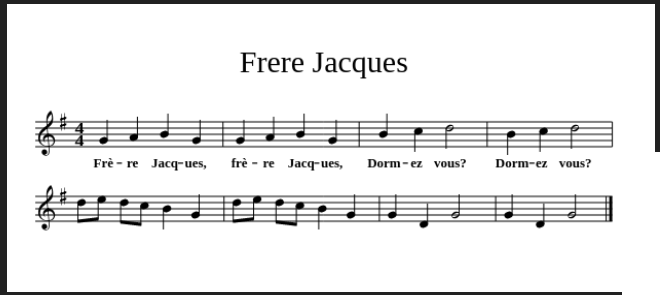
- An interesting fact is that these conditions are enormously effective for learning.

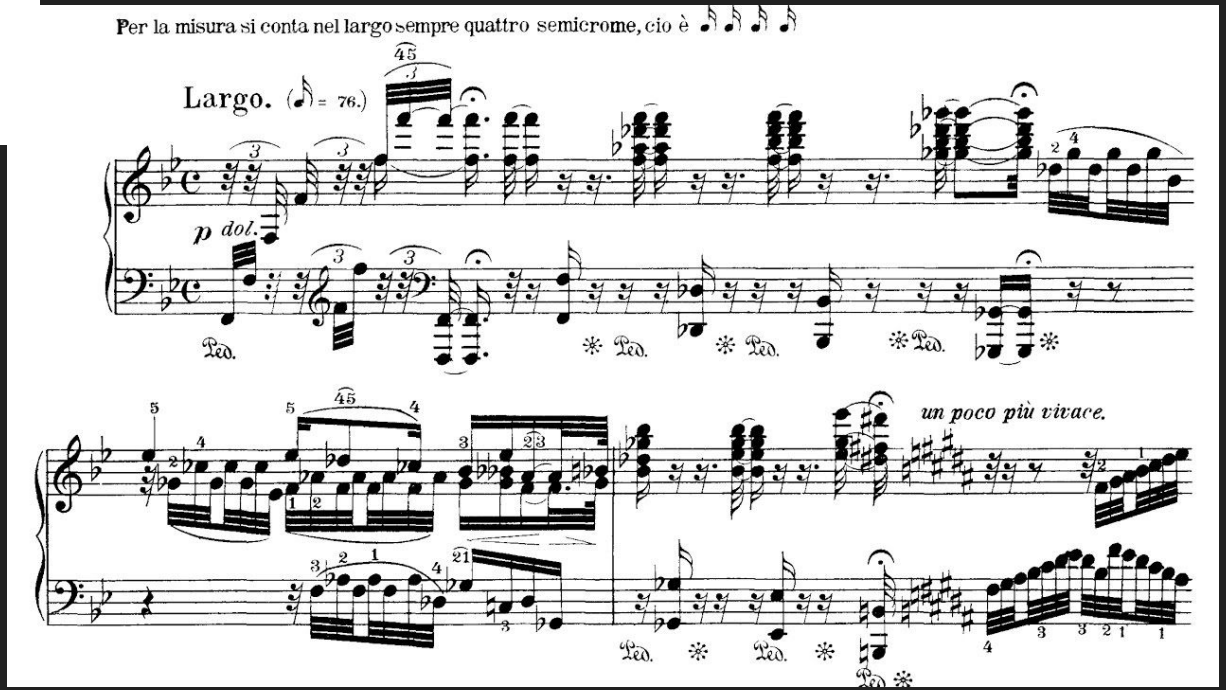
Zone of Proximal Development

- Adapt the challenge level to keep students in the ZPD or “Zone of Proximal Development”.



Zone of Proximal development





How to guide students

Students have different

- background knowledge (maybe Hammerklavier *was* a good next option!)
- learning objectives (e.g. interests)
- learning styles (e.g. example based vs. theory first)
- characters (e.g. extravert vs. intravert)
- attention spans, learning speeds...
- ...

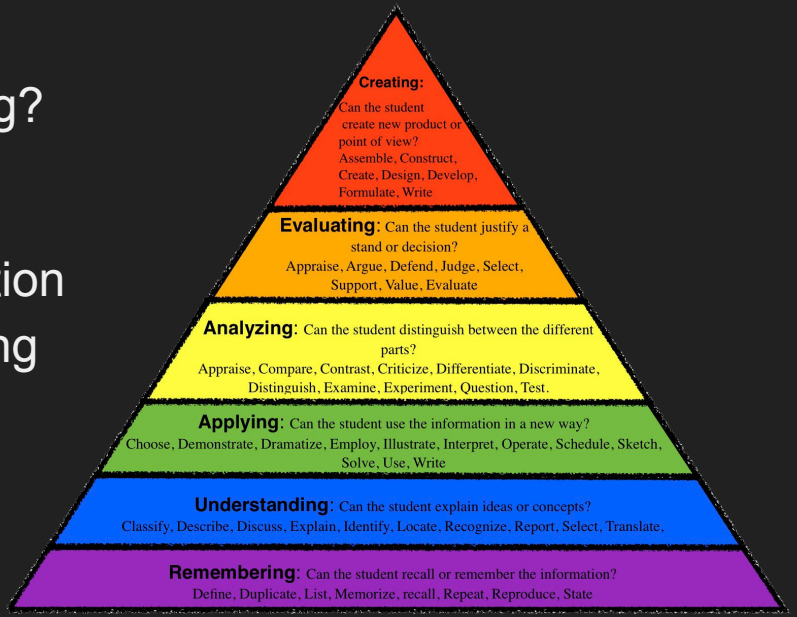
Personalisation is key to guide students.

This is why personalized tutoring is so effective!

What/when has a student learnt?

How do we know someone has learnt something?

- Different “**levels**” of understanding.
- More fundamental research issue in education
- Field of learning analytics / student modelling



Typically we try to measure what someone knows through **learning proxies.**

⇒ what kind of understanding do we test with multiple choice questions?

Representing domain knowledge

An intelligent tutor must be able:

- to represent the domain knowledge,
- reason on it,
- to offer explanations (feedback!)
- to generate new problems adapted to students' needs and
- to model imperfect understanding
- to correct mistakes made by students.

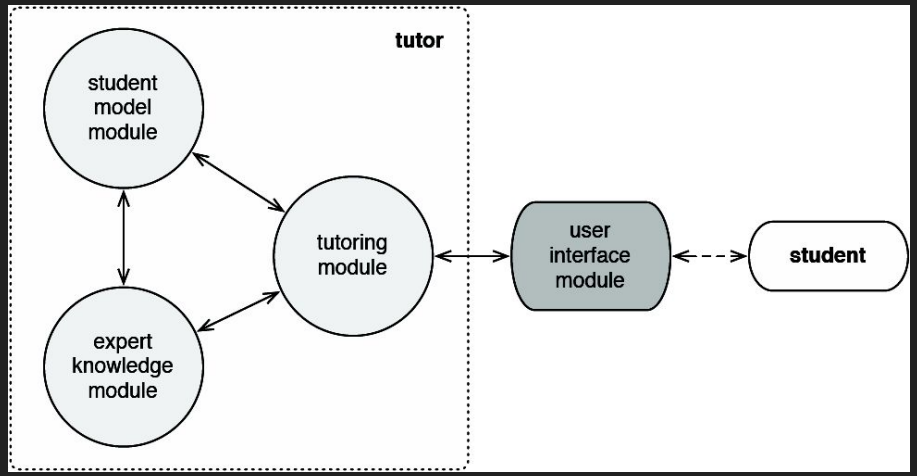
Teaching >> knowledge transfer

A virtual tutor must

- understand what he/she is teaching (content knowledge);
- understand how students learn and how to teach (pedagogical knowledge);
- know how to deliver this information through technology
- keep students motivated

LEARNING:

- cognitive skills
- non-cognitive skills
- meta-cognitive skills



Part II: Approach

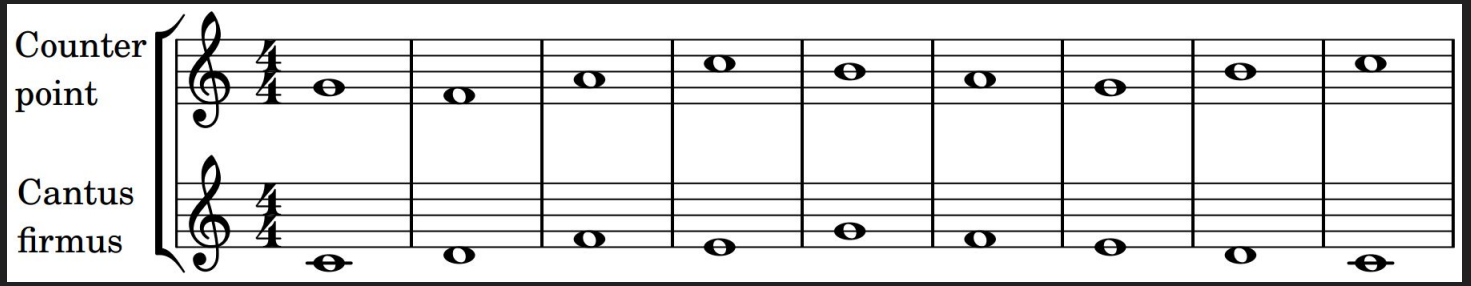
Part III: Case study “counterpoint”

Case study: counterpoint

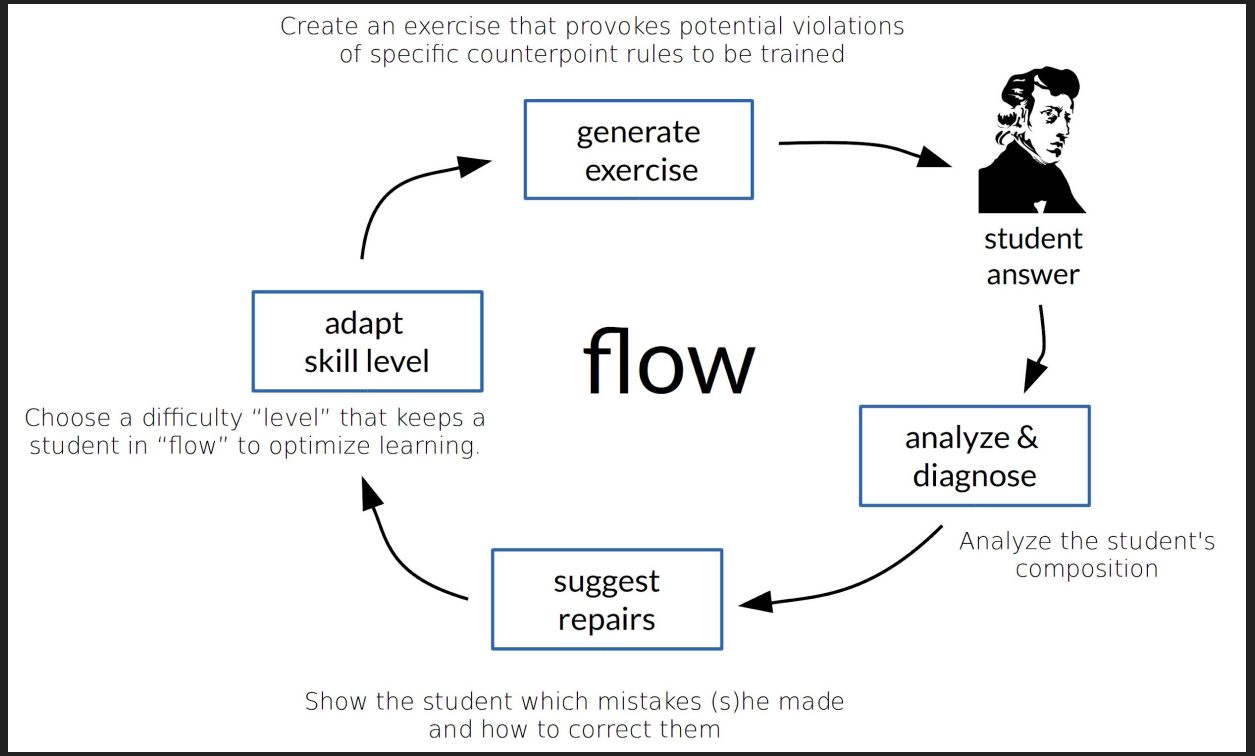
Tool for teaching the many interactions that occur in melodious polyphonic music. Composing is a “design discipline”.

Rules that limit the compositional freedom of a student composer

- Harmonic or vertical constraints (spanning two voices, at one point in time)
- Melodic or horizontal rules (concerning one voice over time)
- Motion rules (relative movement of two voices)



Overview tutoring system



Agent-based architecture

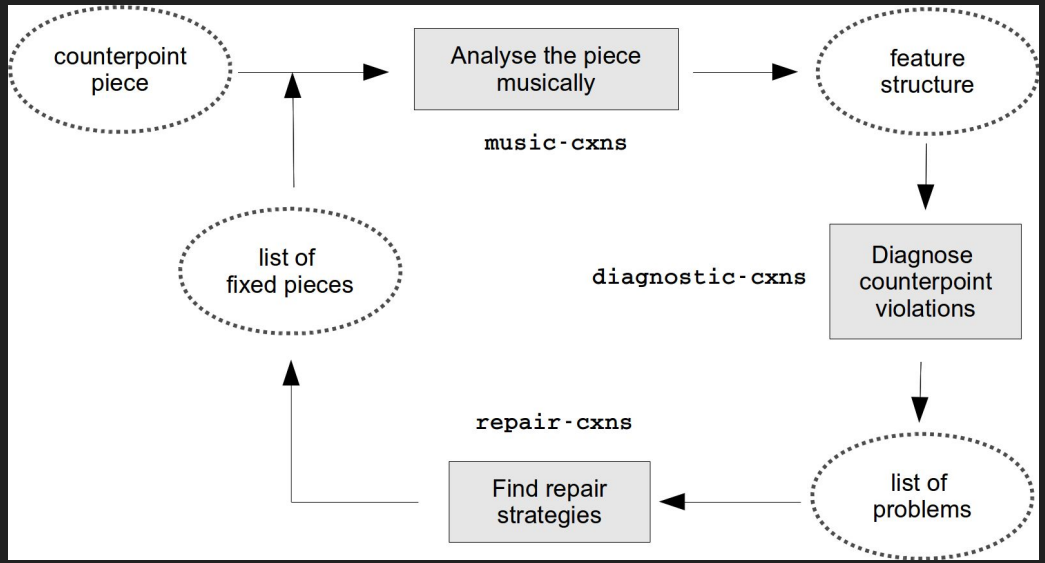
Ultimate goal:

- active student agent that can simulate the learner;
- tutoring agent that can teach, based on this model

Common representation of knowledge that can also model imperfect understanding

Counterpoint tutor agent

1. Musical analysis of the student piece
2. Diagnosing counterpoint violations
3. Applying repair strategies onto these violations



Fluid Construction Grammar (FCG)

Transduction engine + hierarchy and structure building operators

Fundamental differences w.r.t traditional context free grammars:

- No sharp distinction between idiomatic and general rules
- Continuum in the hierarchy and domain of rules (no strict trees)
- Schematisation through variable binding and categorisation
- Constructions can be combined or integrated

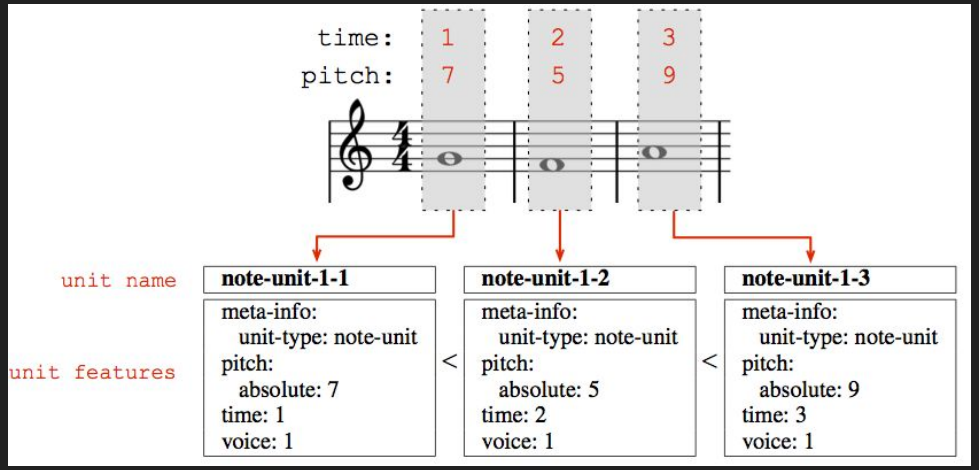
Student knowledge is represented as the set of (grammatical) rules that (s)he masters.

Two basic data structures

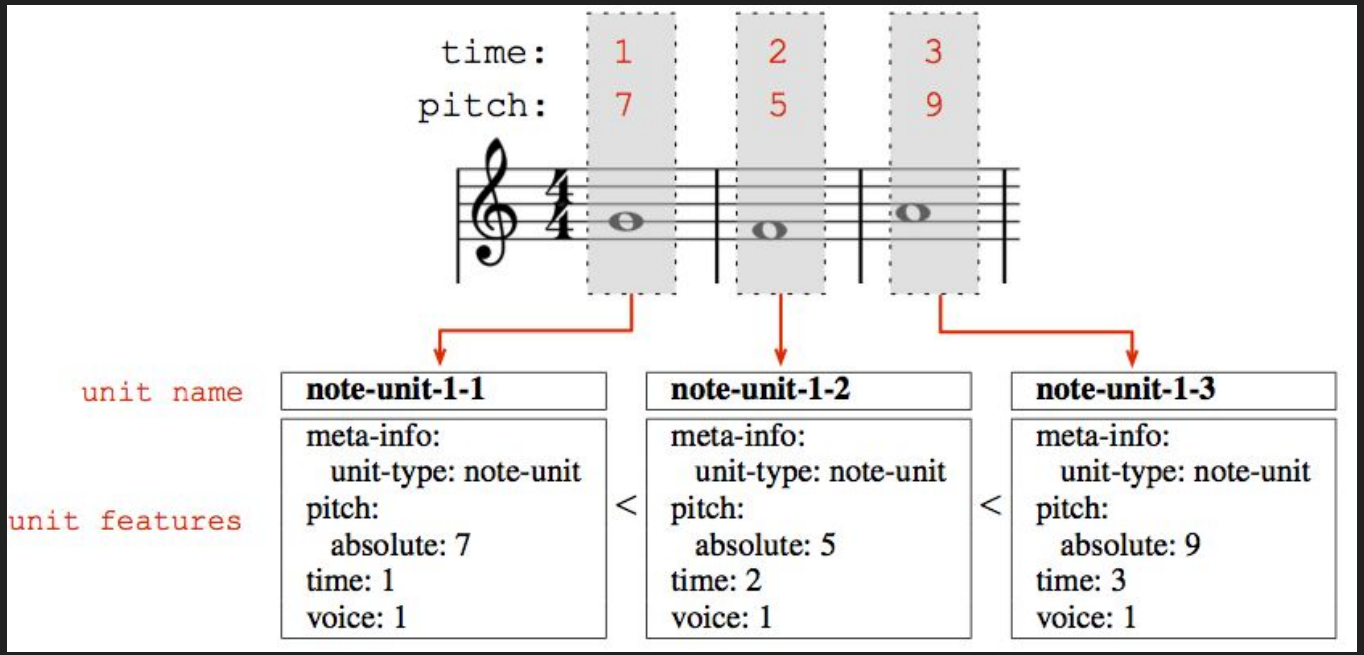
1. Transient structures
2. Constructions

Transient structure built up by applying constructions in a step-by-step fashion

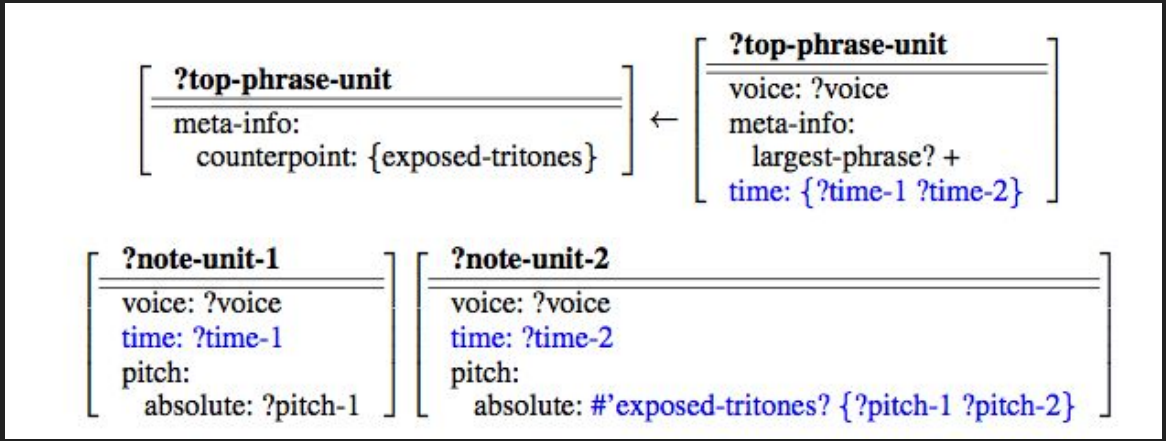
Both consist of units that group information about a meaningful data entity in terms of feature-value pairs



Initial transient structure contains note units



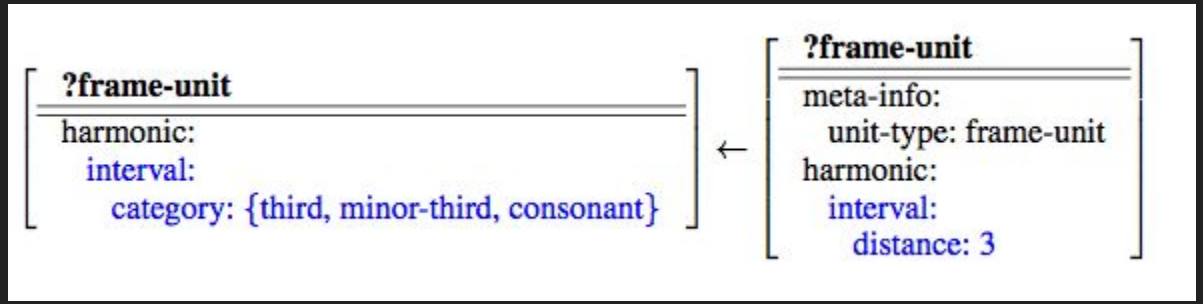
Exposed tritones diagnostic



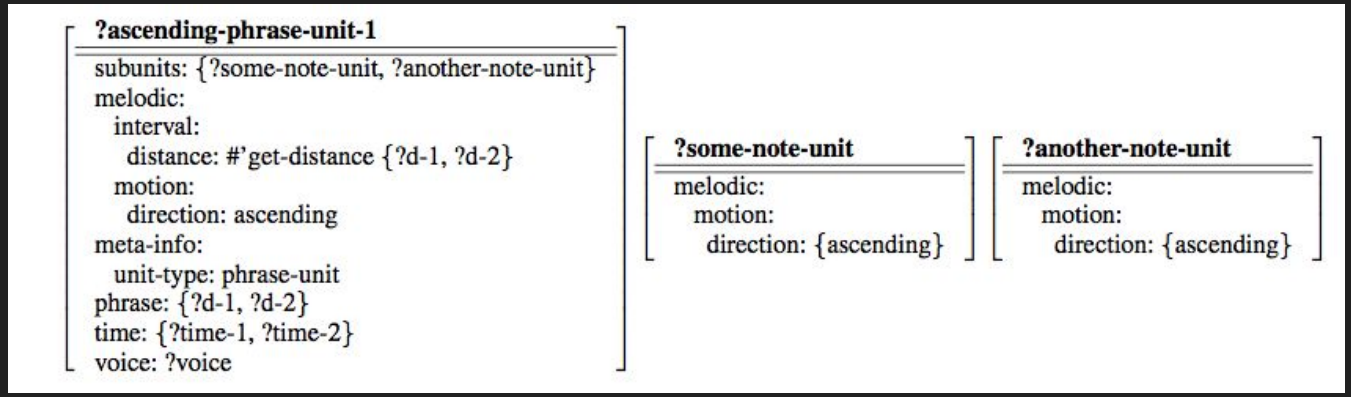
A construction has two parts

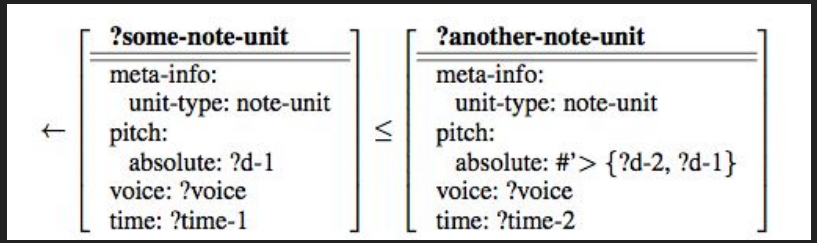
contributing

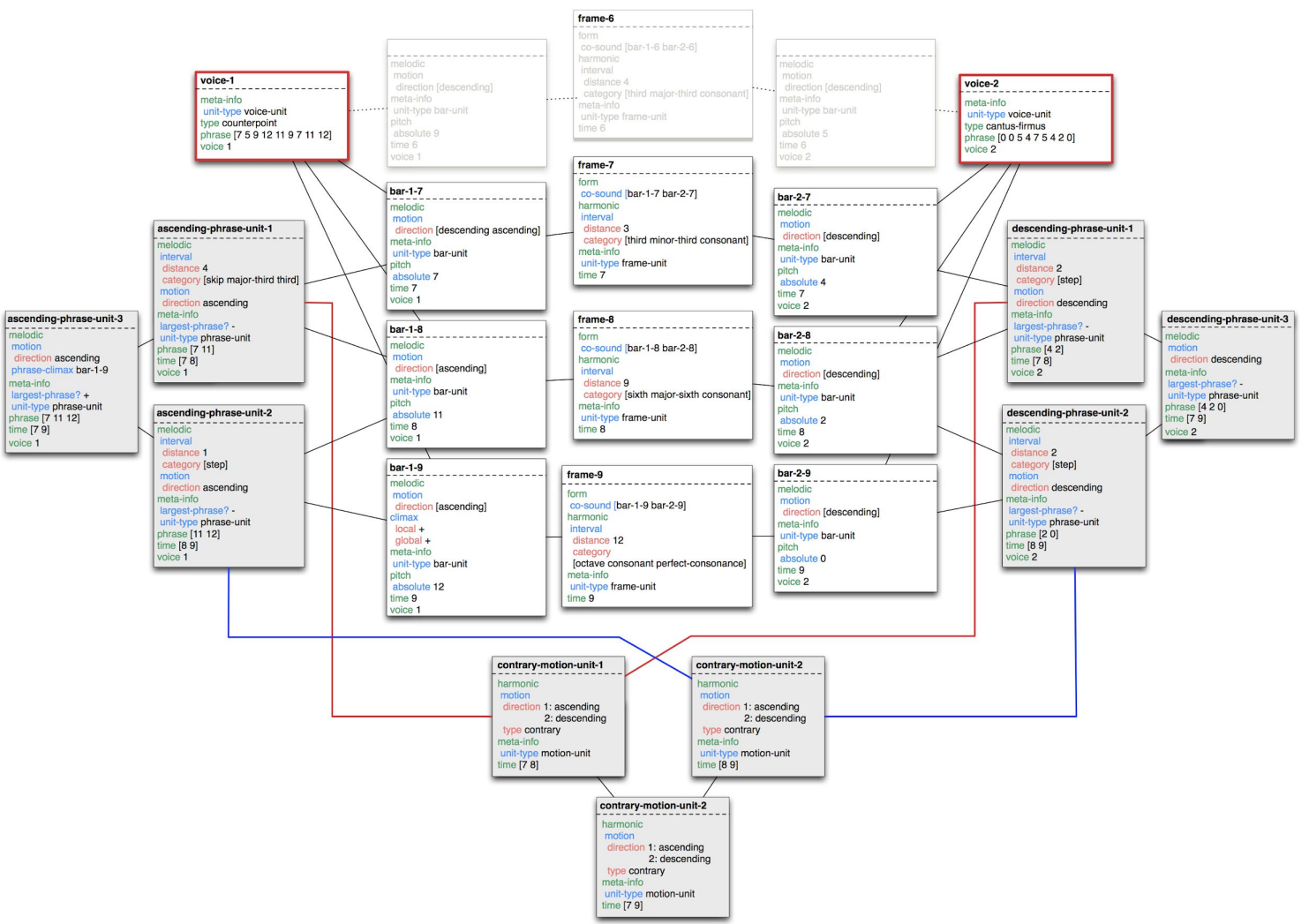
conditional



A construction introduces new features and units to the transient structure





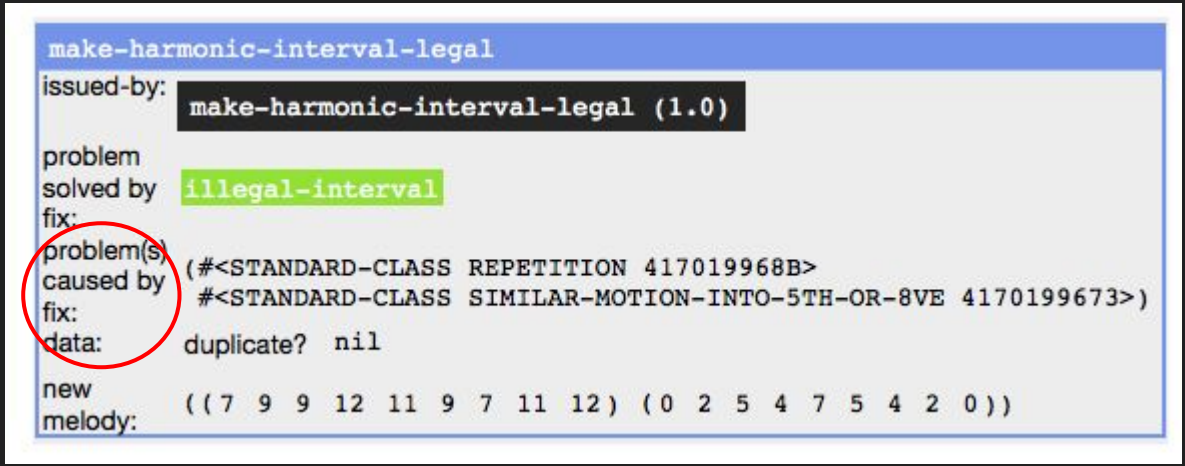

voice-1
meta-info
unit-type voice-unit
type counterpoint
phrase [7 5 9 12 11 9 7 11 12]
voice 1
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 9
time 6
voice 1
frame-6
form
co-sound [bar-1-6 bar-2-6]
harmonic
interval
distance 4
category [third major-third consonant]
meta-info
unit-type frame-unit
time 6
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 5
time 6
voice 2
voice-2
meta-info
unit-type voice-unit
type cantus-firmus
phrase [0 0 5 4 7 5 4 2 0]
voice 2
bar-1-7
melodic
motion
direction [descending ascending]
meta-info
unit-type bar-unit
pitch
absolute 7
time 7
voice 1
frame-7
form
co-sound [bar-1-7 bar-2-7]
harmonic
interval
distance 3
category [third minor-third consonant]
meta-info
unit-type frame-unit
time 7
bar-2-7
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 4
time 7
voice 2
ascending-phrase-unit-1
melodic
interval
distance 4
category [skip major-third third]
motion
direction ascending
meta-info
largest-phrase? -
unit-type phrase-unit
phrase [7 11]
time [7 8]
voice 1
descending-phrase-unit-1
melodic
interval
distance 2
category [step]
motion
direction descending
meta-info
largest-phrase? -
unit-type phrase-unit
phrase [4 2]
time [7 8]
voice 2
ascending-phrase-unit-3
melodic
motion
direction ascending
phrase-climax bar-1-9
meta-info
largest-phrase? +
unit-type phrase-unit
phrase [7 11 12]
time [7 9]
voice 1
bar-1-8
melodic
motion
direction [ascending]
meta-info
unit-type bar-unit
pitch
absolute 11
time 8
voice 1
frame-8
form
co-sound [bar-1-8 bar-2-8]
harmonic
interval
distance 9
category [sixth major-sixth consonant]
meta-info
unit-type frame-unit
time 8
bar-2-8
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 2
time 8
voice 2
descending-phrase-unit-3
melodic
motion
direction descending
meta-info
largest-phrase? -
unit-type phrase-unit
phrase [4 2 0]
time [7 9]
voice 2
ascending-phrase-unit-2
melodic
interval
distance 1
category [step]
motion
direction ascending
meta-info
largest-phrase? -
unit-type phrase-unit
phrase [11 12]
time [8 9]
voice 1
bar-1-9
melodic
motion
direction [ascending]
climax
local +
global +
meta-info
unit-type bar-unit
pitch
absolute 12
time 9
voice 1
frame-9
form
co-sound [bar-1-9 bar-2-9]
harmonic
interval
distance 12
category
[octave consonant perfect-consonance]
meta-info
unit-type frame-unit
time 9
bar-2-9
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 0
time 9
voice 2
descending-phrase-unit-2
melodic
interval
distance 2
category [step]
motion
direction descending
meta-info
largest-phrase? -
unit-type phrase-unit
phrase [2 0]
time [8 9]
voice 2
contrary-motion-unit-1
harmonic
motion
direction 1: ascending
2: descending
type contrary
meta-info
unit-type motion-unit
time [7 8]
contrary-motion-unit-2
harmonic
motion
direction 1: ascending
2: descending
type contrary
meta-info
unit-type motion-unit
time [8 9]
contrary-motion-unit-2
harmonic
motion
direction 1: ascending
2: descending
type contrary
meta-info
unit-type motion-unit
time [7 9]

Finding *pedagogically sound* repairs

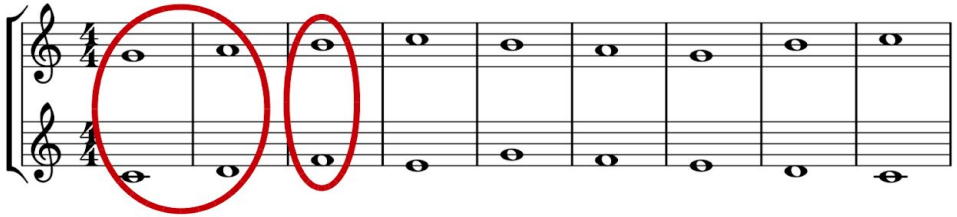
- Make harmonic interval legal (illegal interval)
- Make melodic interval legal (tritone, leap bigger than major sixth)
- Make one leap into step (two leaps in same direction)
- Modify phrase initial/final (exposed-tritones, similar motion, repetition
- Compensate leap (no leap compensation)

Centralise climax, remove one climax, mirror motions, etc.

Fix can solve problems but also cause problems...



TUTOR exercise

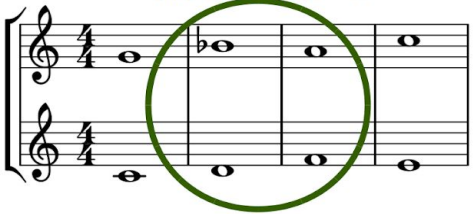


STUDENT answer

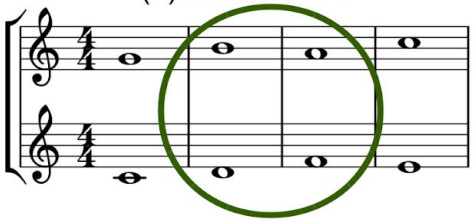
Contains two mistakes : a parallel consonance (M1-M2) and a forbidden interval in M3

The tutor spots the errors and proposes different fixes, in order of complexity (first 4 bars shown only)

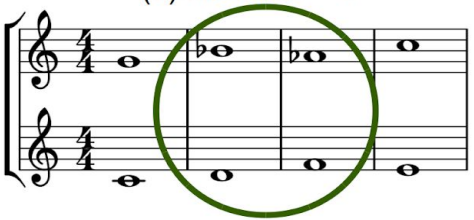
(1) distance = 3



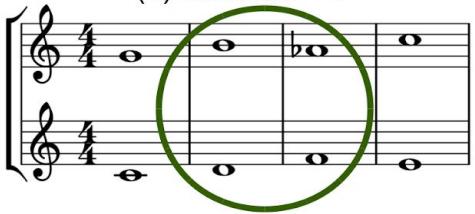
(2) distance = 4



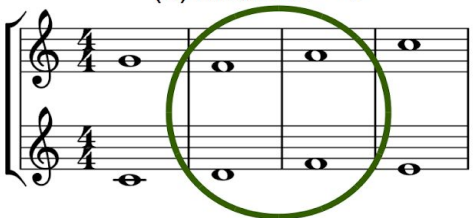
(3) distance = 4



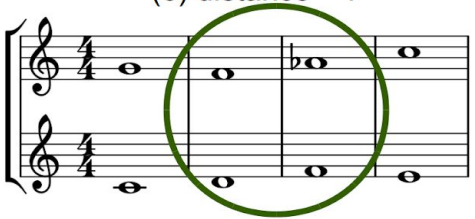
(4) distance = 5



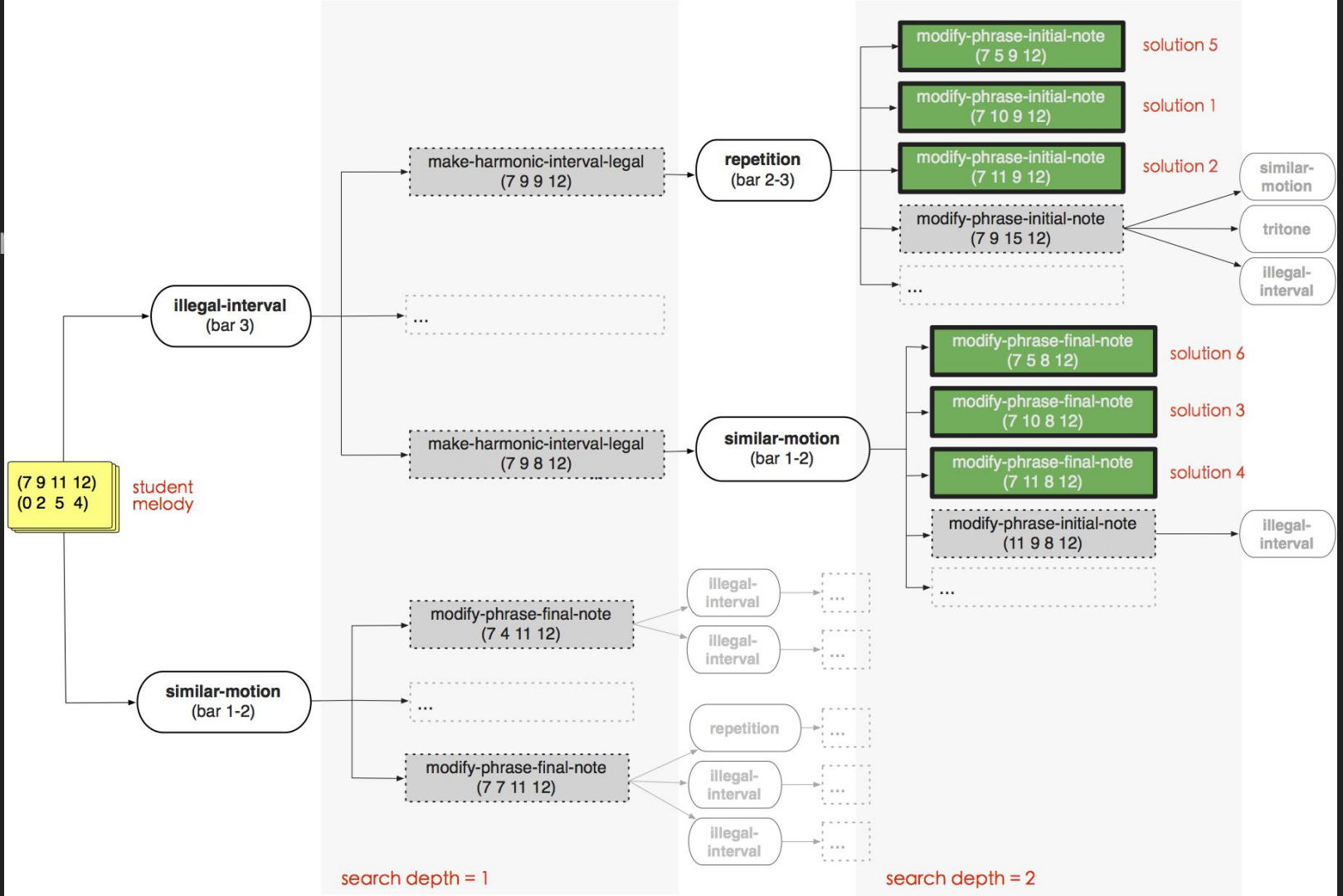
(5) distance = 6



(6) distance = 7



sear

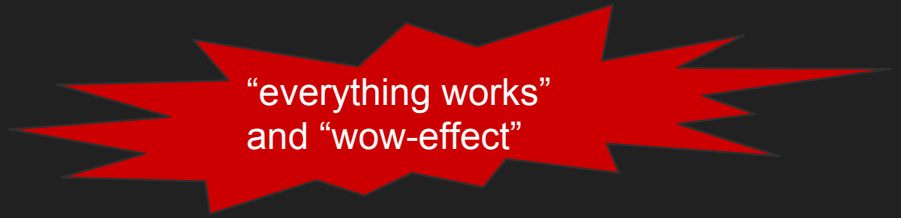

(7 9 11 12)
(0 2 5 4)
student melody
illegal-interval
(bar 3)
similar-motion
(bar 1-2)
make-harmonic-interval-legal
(7 9 9 12)
...
make-harmonic-interval-legal
(7 9 8 12)
repetition
(bar 2-3)
similar-motion
(bar 1-2)
modify-phrase-final-note
(7 4 11 12)
...
modify-phrase-final-note
(7 7 11 12)
modify-phrase-initial-note
(7 5 9 12)
solution 5
modify-phrase-initial-note
(7 10 9 12)
solution 1
modify-phrase-initial-note
(7 11 9 12)
solution 2
modify-phrase-initial-note
(7 9 15 12)
...
similar-motion
tritone
illegal-interval
modify-phrase-final-note
(7 5 8 12)
solution 6
modify-phrase-final-note
(7 10 8 12)
solution 3
modify-phrase-final-note
(7 11 8 12)
solution 4
modify-phrase-initial-note
(11 9 8 12)
...
illegal-interval
illegal-interval
...
illegal-interval
...
repetition
...
illegal-interval
...
illegal-interval
...
search depth = 1
search depth = 2

Conclusions

Conclusions

- Education is in a global crisis (for 30 years now)
- Online / distance education does not profit from technology yet
  - focus too often on technology, not teaching / learning (with UX / UI design in the 80ies)
  - divide between pedagogy &
- AI can contribute significantly
- Many exciting challenges
  - providing personalized learning experiences (to achieve scalability)
  - how to measure learning?
  - how to represent knowlege?
  - intelligent tuturing strategies (when to give what feedback)

Ideas



- Evaluation
  - Common problem in education: many influencing factors
  - Expert evaluation: blind test, rating human & computer feedback
  - Experiment with students
- Improve efficiency of search through better repairs & heuristics
- More fine-grained control over exercise complexity (e.g.
- Active student model that can also produce solutions

References

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