Intelligent tutoring systems

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Outline

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PART I: Context & history

AI and education: a long history

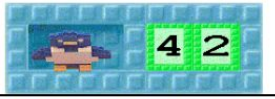
LOGO was conceived as a learning environment, based on the constructivist theory of Jean Piaget, that considers learning as a process in which learners *create knowledge* in their minds as they *interact* with things and people in the world around them.

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 

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

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

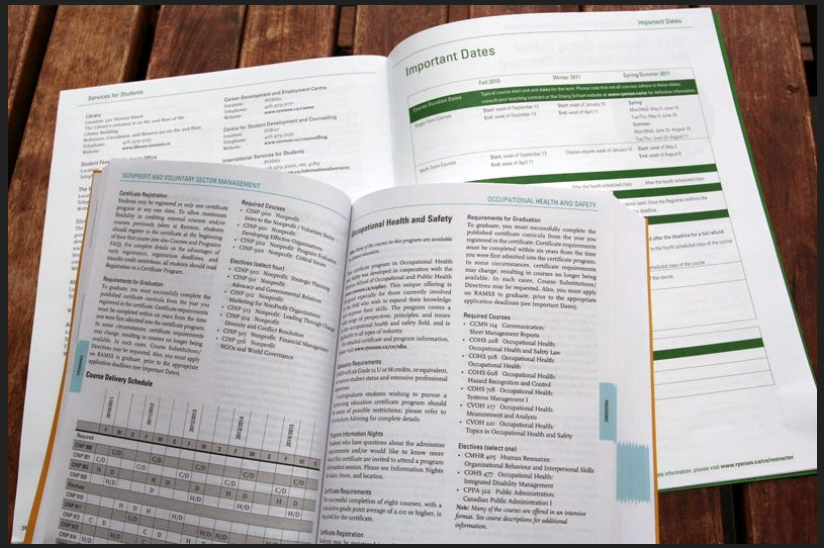
- Our methods of teaching are outdated! A lot is known, but the wheel is reinvented all the time. (E.g. Rovio)

Second: Maybe the time is right?

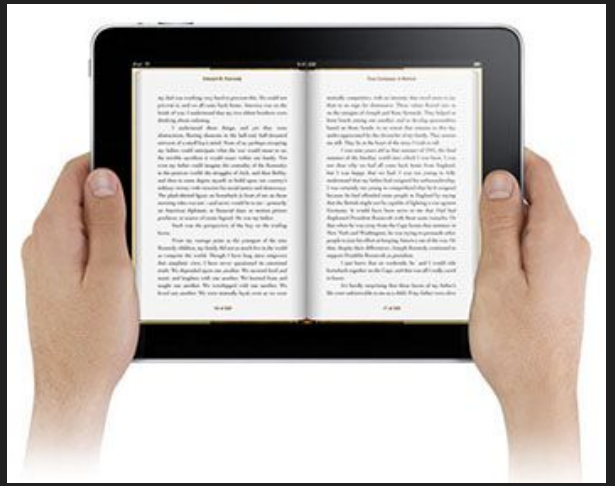
- **Sociological evolutions**
  - First generations of “digital natives”: participative culture
  - Techno-utopian age, political inertia

- **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.



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

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”

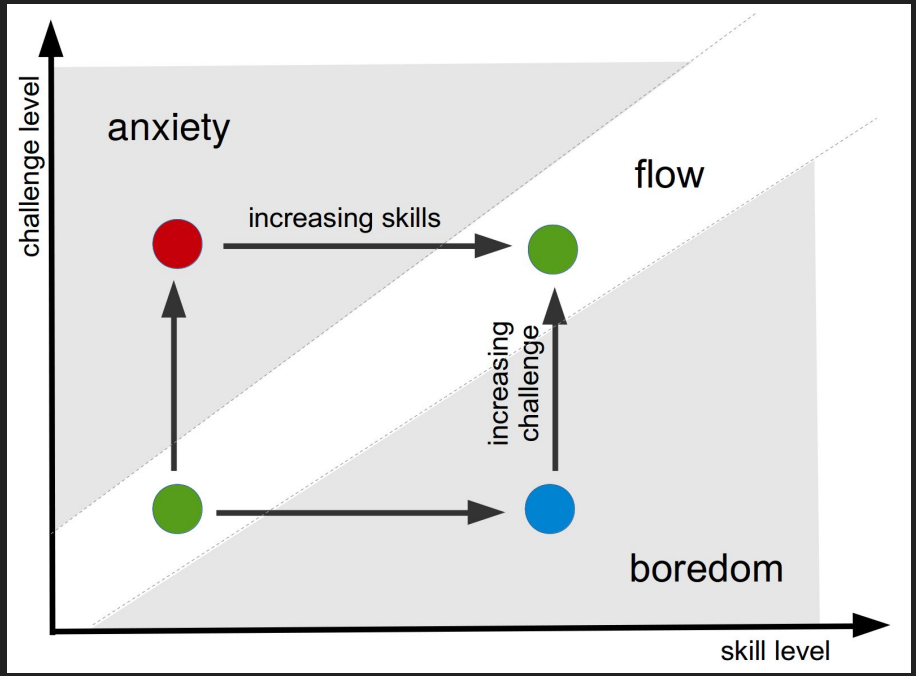
- Flow describes the situation in which people reach an optimal experience of **extreme focus of psychic energy**, high achievement, feeling of creativity, rapid learning and happiness.

- 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”.



How to guide students

Students have different

- learning objectives (e.g. interests)
- learning styles (e.g. example based vs. theory first)
- characters (e.g. extravert vs. intravert)
- attention spans
- ...

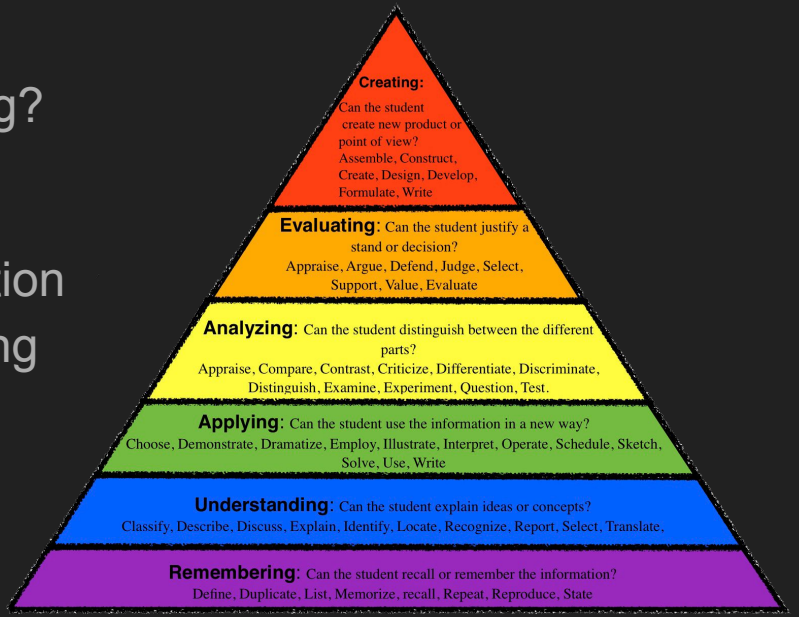
Personalisation is key to guide students.

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,
- to generate new problems adapted to students' needs and
- to model imperfect understanding
- to correct mistakes made by students.

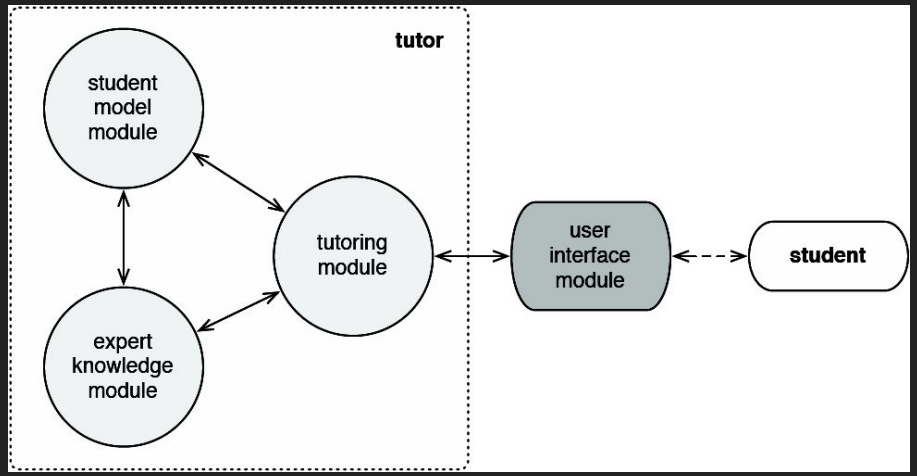
Teaching >> knowledge transfer

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

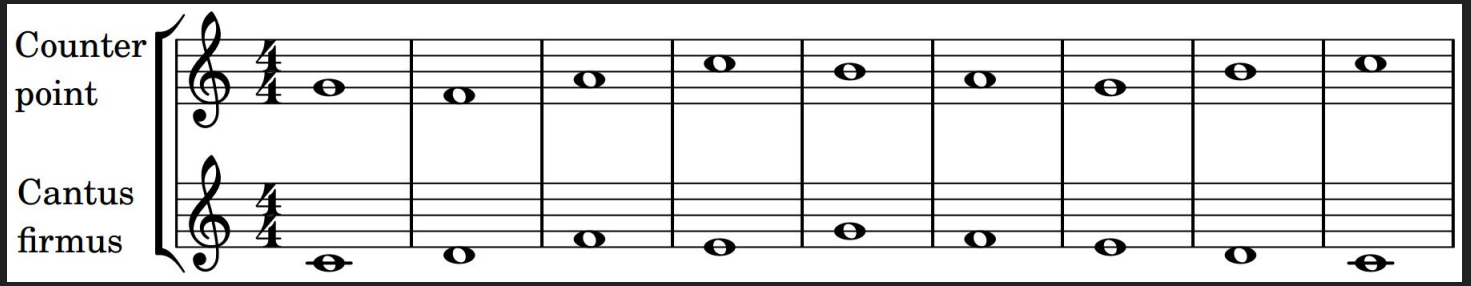
Part III: Case study “counterpoint”

Case study: counterpoint

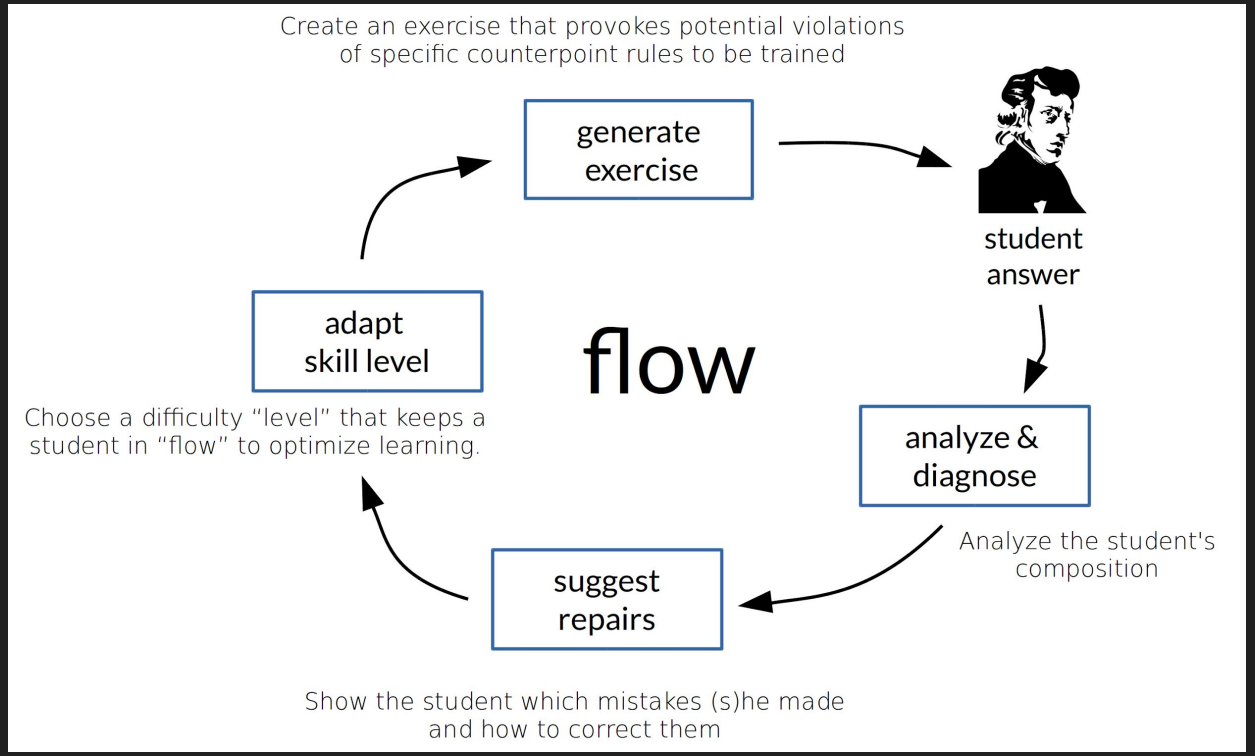
Tool for teaching the many interactions that occur in melodious polyphonic music. Composing is a “design discipline”.

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

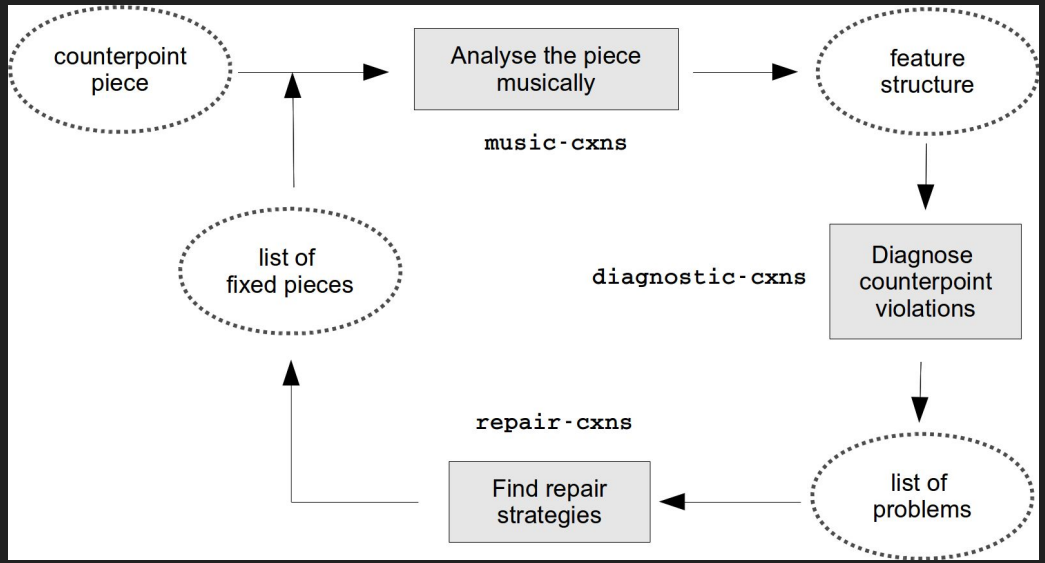
Ultimate goal:

- 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

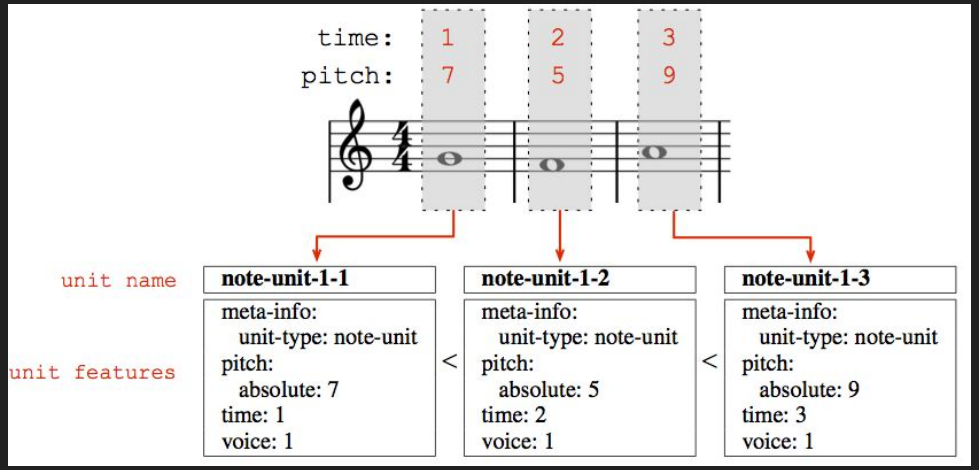
Student knowledge is represented as the set of (grammatical) rules that (s)he masters.

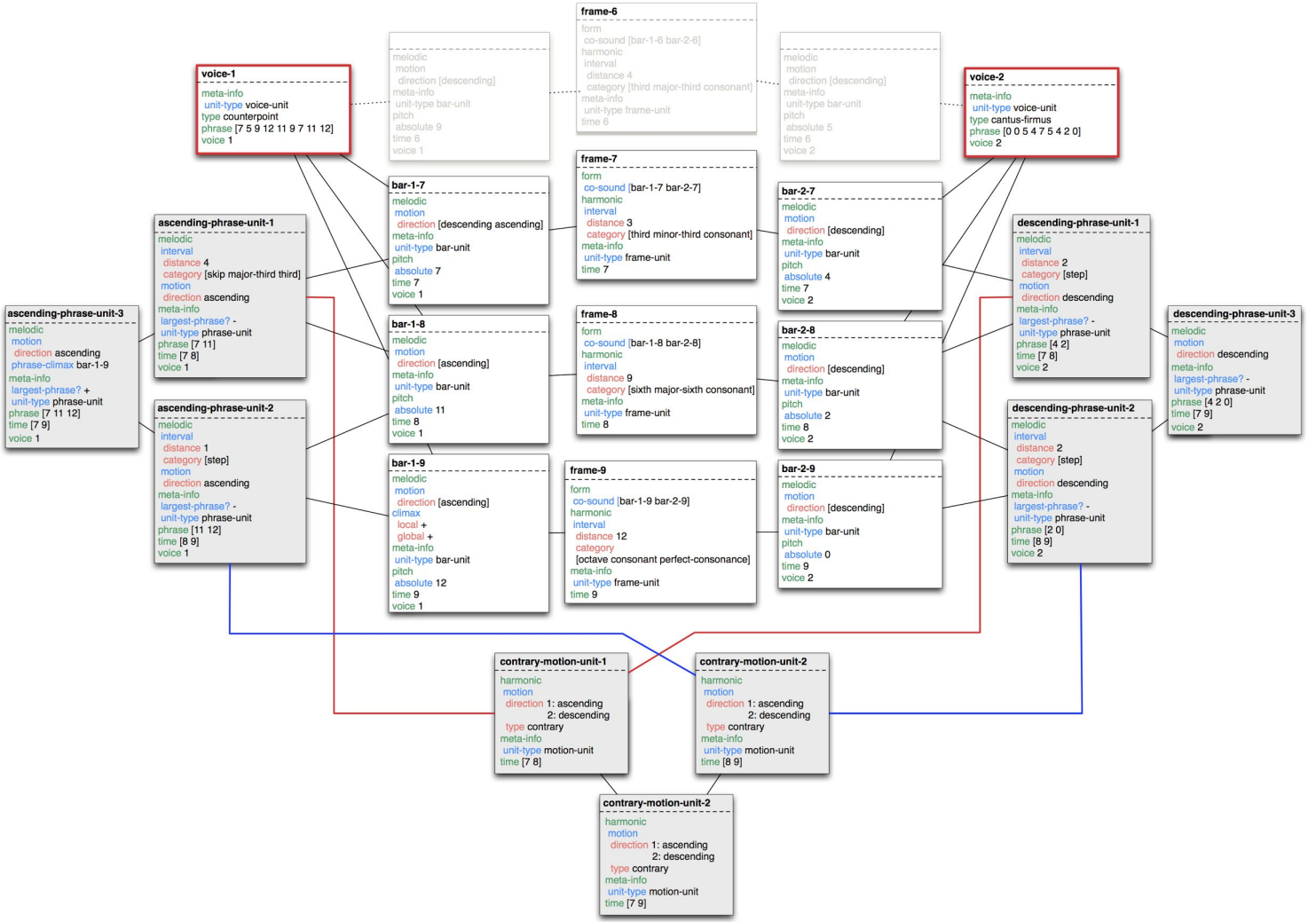
Two basic data structures

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



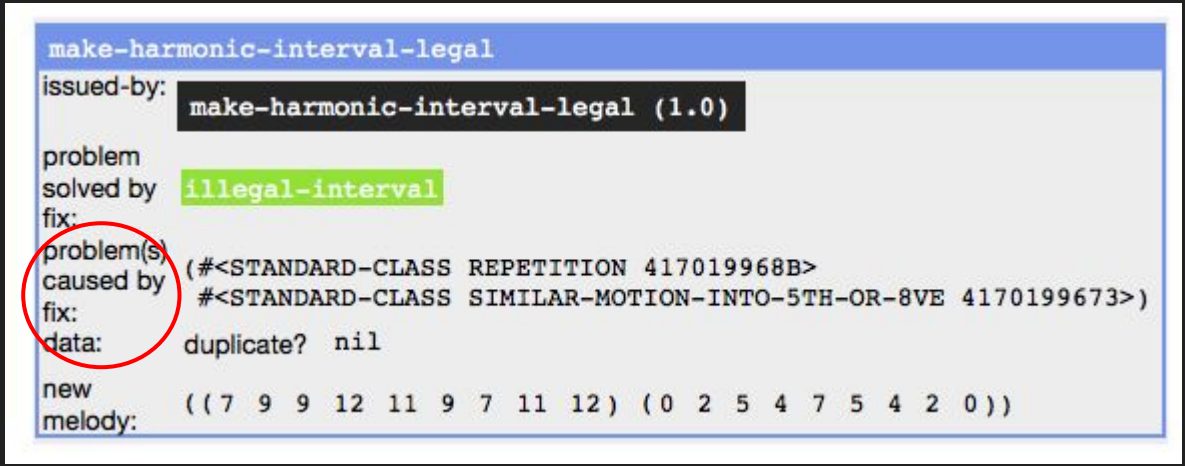

voice-1
meta-info
unit-type voice-unit
type counterpoint
phrase [7 5 9 12 11 9 7 11 12]
voice 1
melodic
motion
direction [descending]
meta-info
unit-type bar-unit
pitch
absolute 9
time 6
voice 1
frame-6
form
co-sound [bar-1-6 bar-2-6]
harmonic
interval
distance 4
category [third major-third consonant]
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
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
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
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

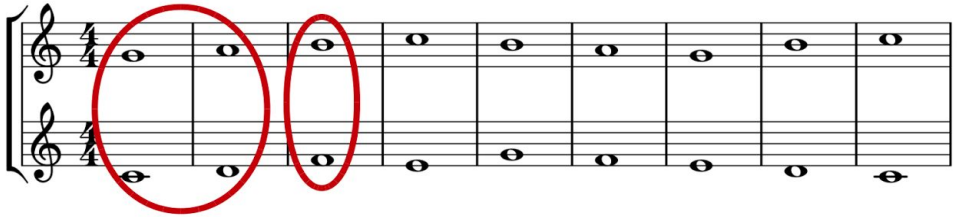
- Make harmonic interval legal (illegal interval)
- Make melodic interval legal (tritone, leap bigger than major sixth)
- Make one leap into step (two leaps in same direction)
- Modify phrase initial/final (exposed-tritones, similar motion, repetition
- Compensate leap (no leap compensation)

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

Fix can solve problems but also cause problems...



TUTOR exercise

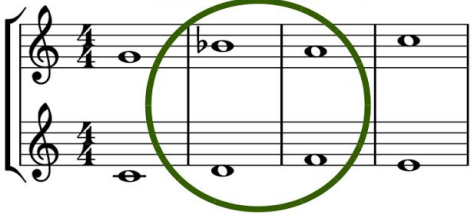


STUDENT answer

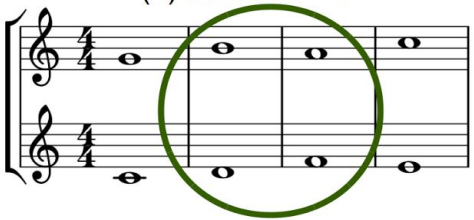
Contains two mistakes : a parallel consonance (M1-M2) and a forbidden interval in M3

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

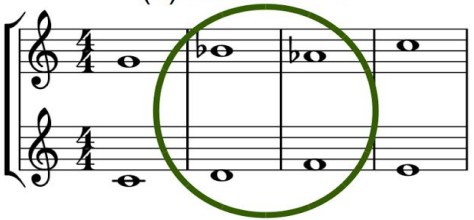
(1) distance = 3



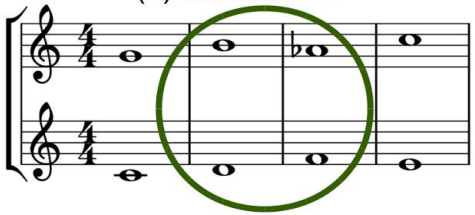
(2) distance = 4



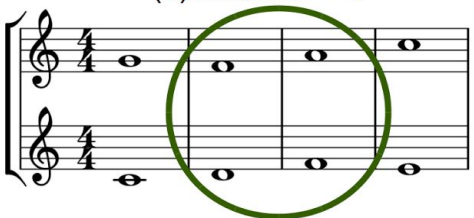
(3) distance = 4



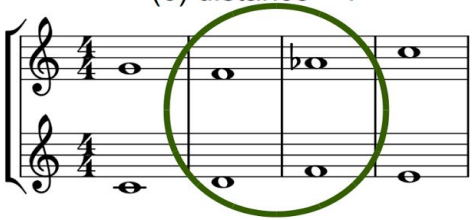
(4) distance = 5



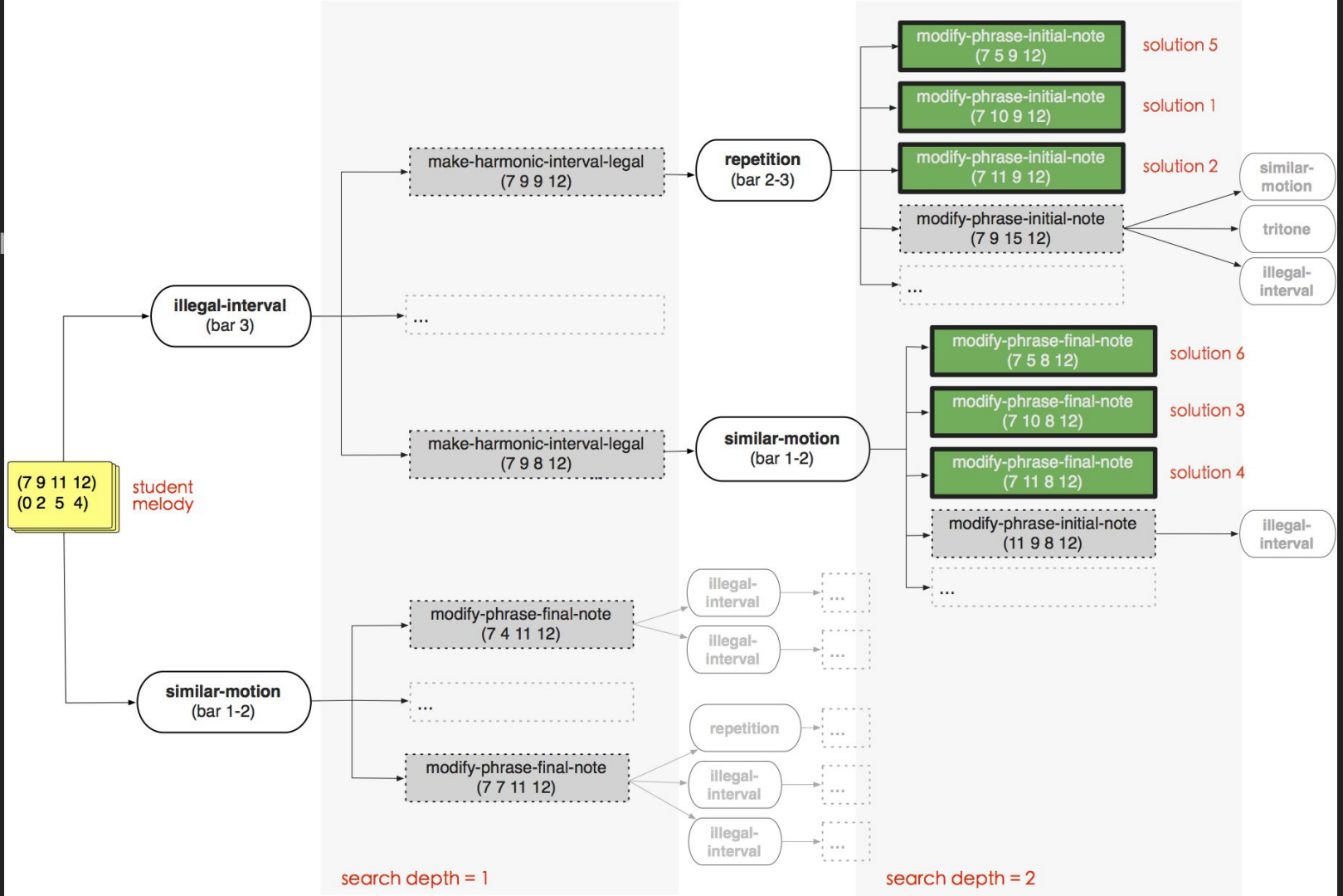
(5) distance = 6



(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)

Future work

- 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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Gee, J. P. (2003). What video games have to teach us about learning and literacy. Computers in Entertainment (CIE), 1(1), 20-20.

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Kohn, A. (1999). Punished by rewards: The trouble with gold stars, incentive plans, A's, praise, and other bribes. Houghton Mifflin Harcourt.

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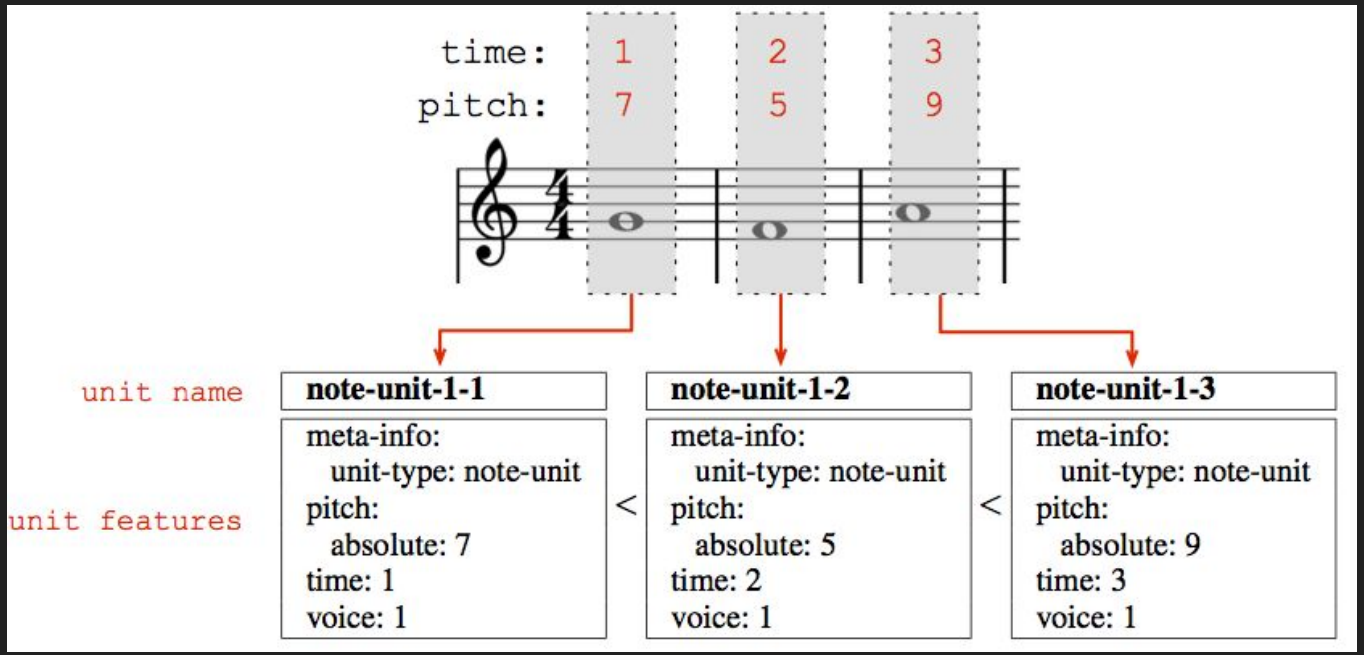
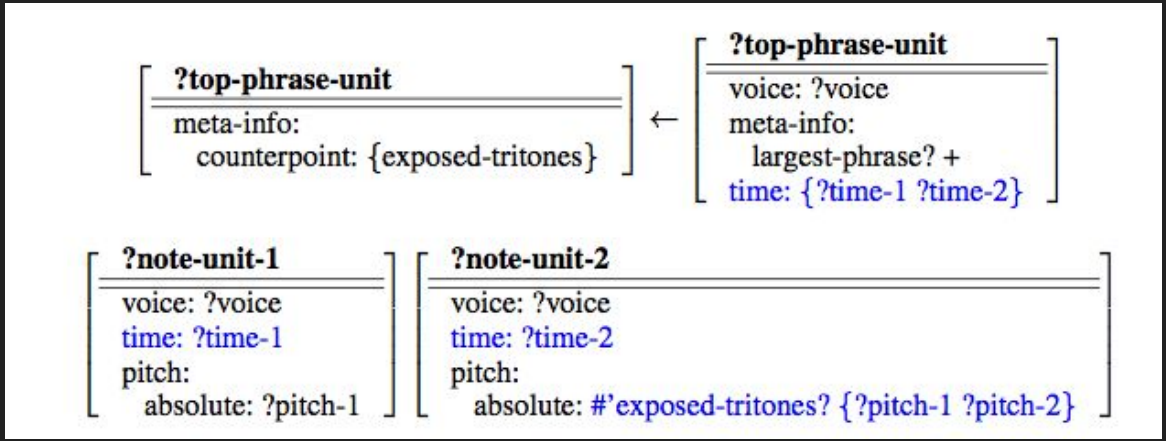
Initial transient structure contains note units



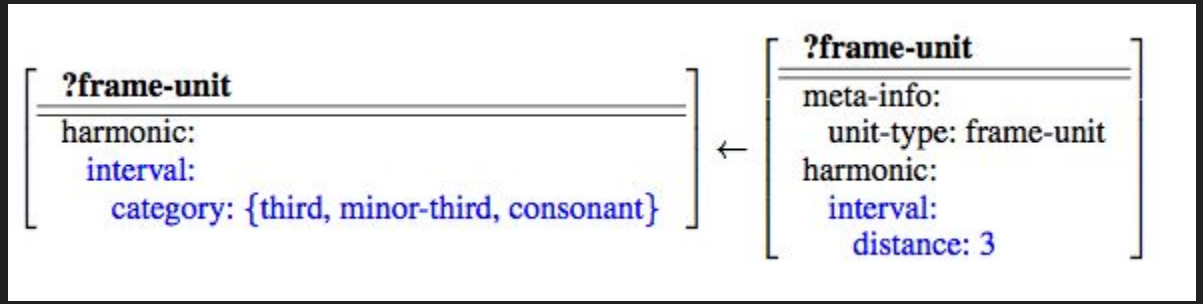
Exposed tritones diagnostic



A construction has two parts

contributing

conditional



A construction introduces new features and units to the transient structure