On Skill Acquisition Support by Analogical Rule Abduction

Koichi Furukawa	Keio University
Keita Kinjo	Okinawa International University
Tomonobu Ozaki	Nihon University
Makoto Haraguchi	Hokkaido University

The Aim of the Research

- To explain why the following discoveries work well.

1. Discovery of rapid bowing technique by bow holding with flexible thumb joint
2. Discovery of spiccato technique by ring finger bow holding
   - https://www.youtube.com/watch?v=cJWjYLG3B7o&feature=related
3. Discovery of one-bow staccato technique by stiff bow holding
   - https://www.youtube.com/watch?v=YOz6XK7jv3Y
4. Explaining effectiveness of metaphorical expression for forte-piano playing

Personal evidence (My performance)

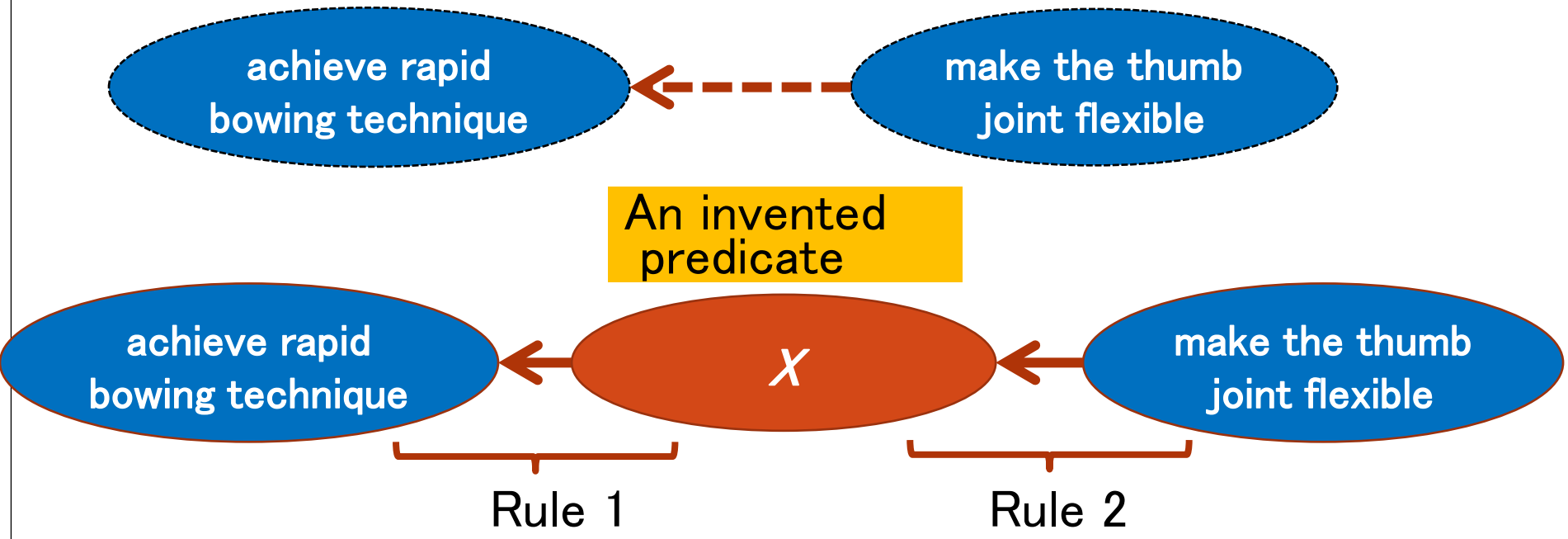
https://www.youtube.com/watch?v=r1qoyQIYt6s
https://www.youtube.com/watch?v=8zAaAQeJuaw
https://www.youtube.com/watch?v=bRTtfVMV3_4

Abduction in Skill Science

- Surprising observation: Knack
  - *Rapid bowing technique is achieved by bow holding with flexible thumb joint.*
- Proof: Explanation
  - *Bow holding with flexible thumb joint causes rapid bowing technique. (by some unknown reason)*
- Abduction: Hypotheses generation to explain the knack

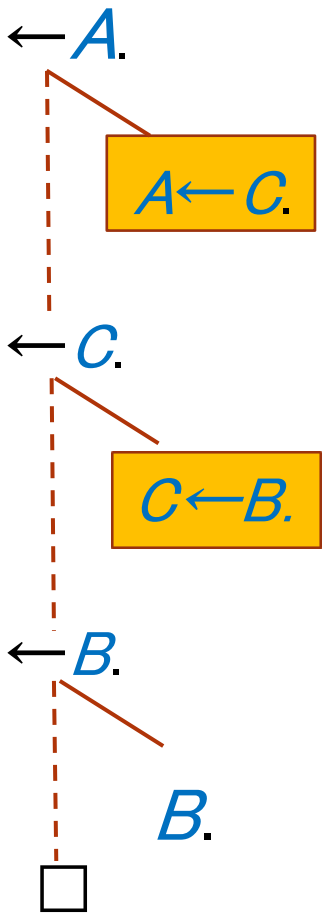
An Example of Rule Abduction

- A given knack: "*Rapid bowing technique is achieved by bow holding with flexible thumb joint.*"
- Hidden rules to be discovered: "*if you make the thumb joint flexible, then you can make all fingers flexible*." and "*if you make all fingers flexible, then you can achieve rapid bowing technique*."



Discovering Hidden Secret by Rule Abduction

- To abduce a hidden reason for the knack "*you should do an action B in order to achieve a task A*", we assert *B* and vainly try to prove the goal *A*.
- The abduction finds missing links connecting the goal *A* and the fact *B*.
- Therefore the abduction should abduce a connection rule, not a fact.
- Meta-level abduction [Inoue 09] can abduce rules.



Inoue, K., Furukawa, K., Kobayashi, I., and Nabeshima, H.: Discovering Rules by Meta-level Abduction, Proc. 19th International Conference on Inductive Logic Programming (ILP 2009), Leuven, Belgium,pp.49-64(2009)

Meta-Level Representation based on Causality Relation

- We represent the object level causalities in terms of first order logic (FOL) clauses representing causalities.

- The direct or indirect causality: “caused(X,Y)”

  caused(achieve_rapid_bowing_technique,
  make_the_thumb_joint_flexible)

- Direct causality: “connected(X,Y)”

  connected(make_all_fingers_flexible,
  make_the_thumb_joint_flexible)

- The definition of “caused”:

  caused(X,Y)←connected(X,Y).
  caused(X,Y)←connected(X,Z)∧caused(Z,Y).

Why Analogy Needed?

- The rule abduction can abduce missing links but cannot give interpretation to the abduced rules.
- In case of predicate invention, the meaning (***make_all_fingers_flexible***) of the invented predicate (***X***) is not given by abduction.

- **Analogical abduction makes it possible to provide understandable interpretation to the introduced predicates/rules.**

Analogical Inference

- **"*b_connected*" :** connectedness in a base world
- **"*t_connected*" :** connectedness in a target world

- We define *b_caused* and *t_caused* as follows:

  $t\_caused(X,Y) \leftarrow t\_connected(X,Y).$
  $t\_caused(X,Y) \leftarrow t\_connected(X,Z) \wedge t\_caused(Z,Y).$
  $b\_caused(X,Y) \leftarrow b\_connected(X,Y).$
  $b\_caused(X,Y) \leftarrow b\_connected(X,Z) \wedge b\_caused(Z,Y).$

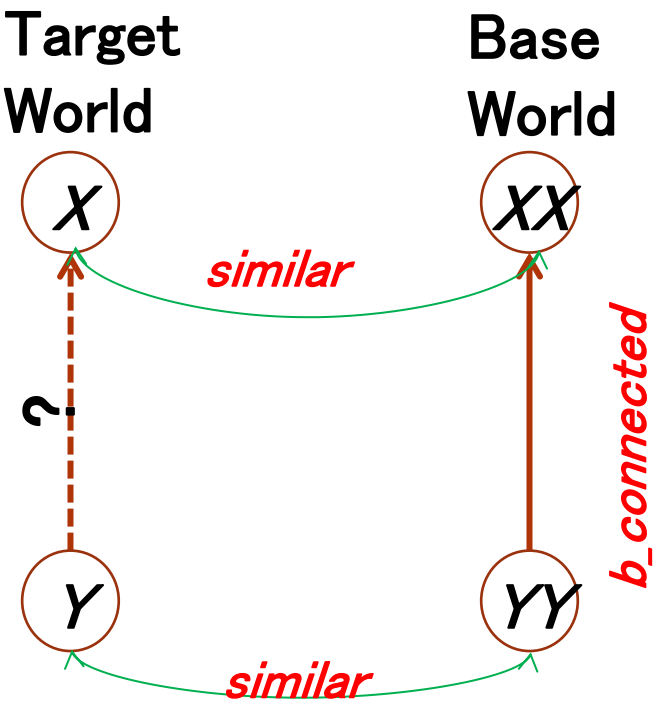
- We represent similarity relationship between a target world atom ***X*** and a base world atom ***XX*** by a predicate **"*similar*(*X*,*XX*)".**

Analogical Axiom

- **Analogy Axiom**

$$connected\_by\_analogy(X,Y) \leftarrow$$
$$b\_connected(XX,YY),$$
$$similar(X,XX),$$
$$similar(Y,YY).$$

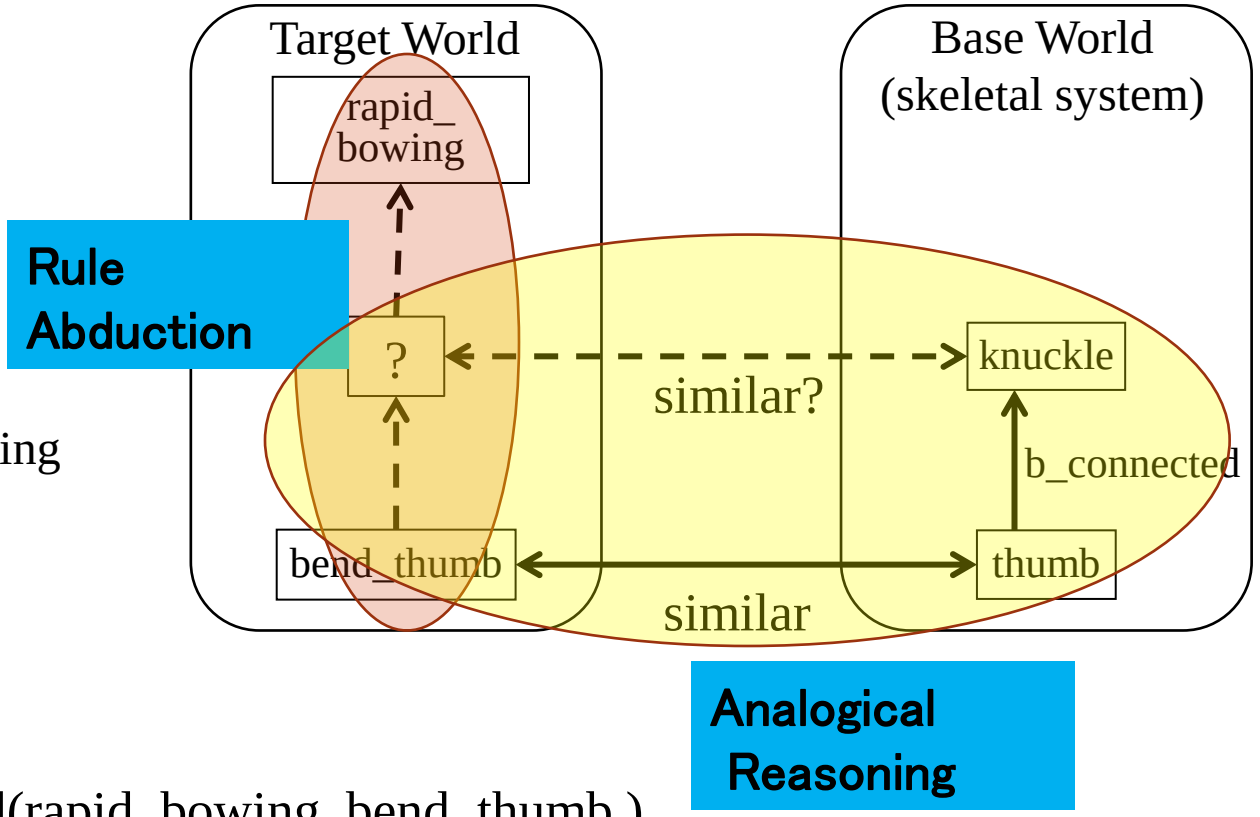
- IF ***b_connected(XX,YY)*** holds at the base world and ***similar(X,XX)*** and ***similar(Y,YY)***, then a causality relation ***connected_by_analogy(X,Y)*** holds at the target world.



Example

- **Problem:**

Explain why "bend_thumb" is effective to achieve rapid_bowing by discovering the analogue between fingers structure and their corresponding finger-bending structure.



- **Program:**

Observation(G)：t_caused(rapid_bowing, bend_thumb).
Abducible literals(Γ)：[connected_directly/2,
similar/2,print_connected_by_analogy/2]
Background knowledge(B)：
Base world： b_connected(knuckle, thumb).
Target world： ←connected_directly(rapid_bowing, bend_thumb).
Similarity： similar(bend_thumb, thumb) .

The meaning of the solution

- One of the six solutions obtained under the inference depth upper limit as 10, hypotheses length limit as 4.

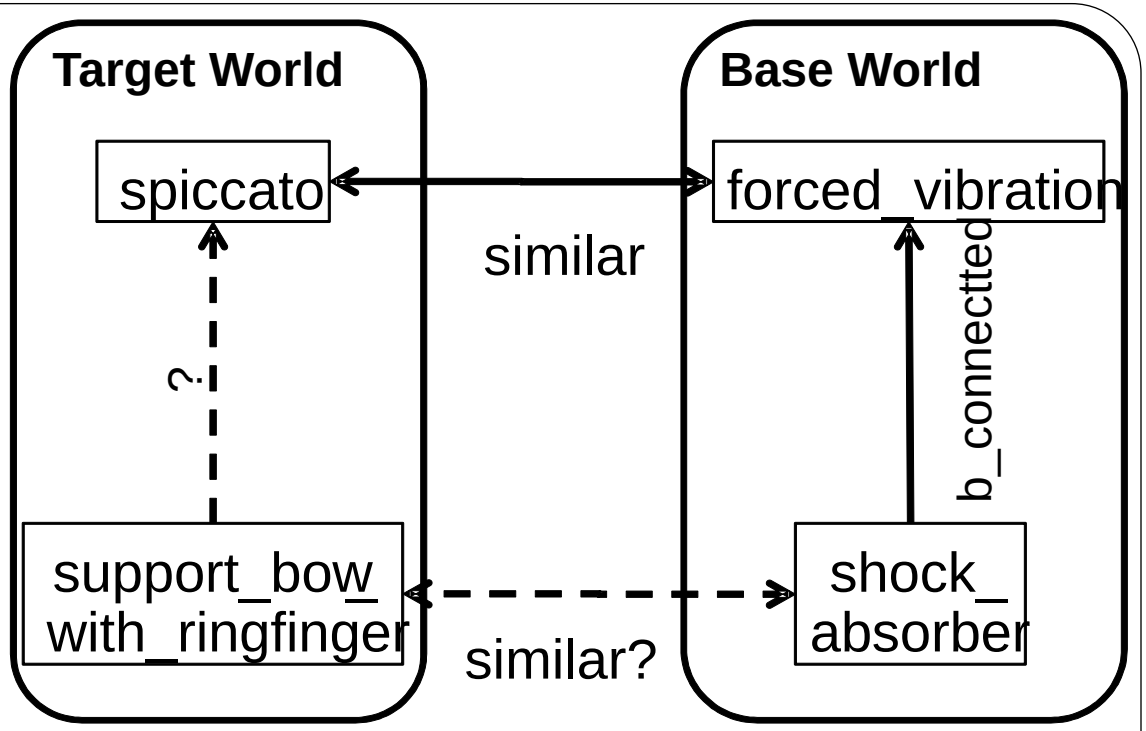
connected_directly(rapid_bowing, _*X*)
∧ similar(_*X*, knuckle)
∧ print_connected_by_analogy(_*X*, bend_thumb)

- The invented predicated _*X* fills the gap between "rapid_bowing" and "bend_thumb" which corresponds to "knuckle" in the finger structure.

- **This suggests that the variable _*X* represents "knuckle fingers bending".**

Spiccato Example

Problem:
Explain the reason why "hold the bow by ring finger" to realize spiccato as "shock absorbing" in forced vibration.



- **Abduction Program :**

Observation(G) : t_caused(spiccato, support_bow_with_ringfinger).

Abducible literals(Γ) : [connected_directly/2, similar/2,print_connected_by_analogy/2]

Background knowledge(B) :

Base world : b_connected(forced_vibration, shock_absorber).

Target world :
←connected_directly(spiccato,support_bow_with_ringfinger).

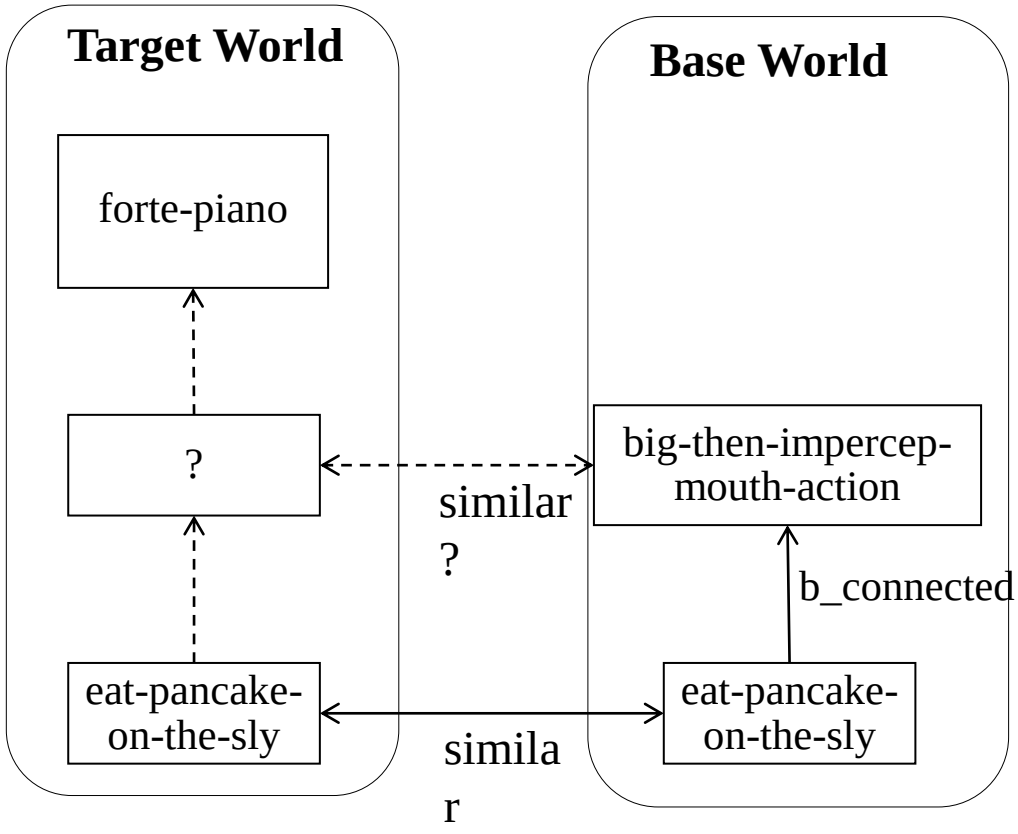
Similarity : similar(spiccato, forced_vibration).

- **Solution :** One of the seven solutions obtained:

print_connected_by_analogy(spiccato, support_bow_with_ringfinger) ∧
similar(support_bow_with_ringfinger, shock_absorber)

Mataphorical expression Example

- Mataphorical expression of
"eating pancake on the sly"
to achieve forte-piano.



Abduction and Analogy as Inference Scheme

- Abduction and analogy are both treated by meta level representation framework.
- They are both kinds of inference in human thinking.
- Our approach suggests human cognitive reasoning behavior can be handled by the meta level reasoning framework.
- Other cognitive activities such persuasive arguments by metaphorical and/or onomatopoeia explanations can be formalized similarly.

Summary

- Rule abduction is essential in skill discovery application.
- Analogical abduction is easily achieved by meta level representation of causality and similarity in the same framework.
- The analogy axiom plays a key role in analogical reasoning.
- Our research suggests a promising approach of cognitive reasoning in skill science.