Sentential Reasoning and Sentential Connectives:
Conditional, Disjunction, Negation, and Modality

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2018-12-16
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The causal conception of reasoning

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- Reasoning is a causal process,
- in which one mental event
  (say, one’s accepting the conclusion of a certain argument)
- is caused by an antecedent mental event
  (say, one’s considering the premises of the argument).

(Wedgwood, 2006)
Core sentential inferences

Major Premise: If the housing market crashes, then the stock market will crash.

Category Premise: The housing market crashes.

Deduction: Therefore, the stock market will crash.

Induction: And so, unemployment will rise.

Abduction: And perhaps consumer debt caused the housing market to crash.

(Khemlani, 2018)
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The case of conditional

Given two atomic propositions: A, B

Asserting the conditional statement: If A, then B

Implies that: The speaker is not in a position to know the two propositions are true.

(Ramsey, 1929; Russell, 1906)
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Possible world and closed box

The Google doodle for Erwin Schrödinger's 126th Birthday
On August 12, 2013
The case of conditionals

You first see two objects, say guzheng and fans. Then you see a test picture.

Each test picture contains four boxes, three of which are open, one is closed. When a box is closed, we do not know what object is inside. But whether the box is open or closed, the box contains one of the aforementioned objects, for example, guzheng or fans.

Each side of the box also has a sticker, say guzheng or fans. If the object in the box and the side sticker are the same (such as the box contains guzheng, the sticker is also guzheng), then the object in the box is genuine and good quality. The person who gets this box (regardless of what is in the box) will be very happy.

If the object in the box and the sticker are different (such as the box contains guzheng, while the sticker is fans), then the object in the box is fake, of poor quality. The person who gets this box (regardless of what is in the box) will be very sad.

In the story, there is a boy named Xiaoming. Xiaoming sometimes opens his own box, sometimes doesn’t. The test sentence describes the box that Xiaoming got.

You need to choose which of A, B, C, D this box is among.
The case of conditionals

- You first will see two objects, such as guzheng and fans. Then you will see a test picture.

  - Every test picture contains four boxes, three of which are open, and one is closed. When the box is closed, we don't know what's inside. But the box, regardless of whether it is open or closed, contains one of the two objects, such as guzheng or fans.

  - Each box wall has a sticker, such as guzheng or fans. If the object inside the box and the sticker on the box wall are the same (e.g. the box contains guzheng, and the sticker on the box is guzheng), then the object inside the box is genuine, and the quality is good. The person who gets this box (regardless of what's inside) will be happy.

  - If the object inside the box and the object on the box wall are different (e.g. the box contains guzheng, and the sticker on the box is fans), then the object inside the box is fake, and the quality is bad. The person who gets this box (regardless of what's inside) will be sad.

- In the story, there is a boy named Xiao Ming who got one of these boxes. Xiao Ming sometimes opened his own box, and sometimes didn't open his own box. The test sentence describes the specific box that Xiao Ming got.

- You need to choose which box (among A, B, C, D) Xiao Ming got.
The case of conditionals

- You first see two objects, such as a guzheng and a fan. Then you see a test picture.
- Each test picture has four boxes, among which three are open and one is closed. When a box is closed, we do not know what object is inside. However, the box regardless of whether it is opened or not, contains one of the above two objects, such as guzheng or fan.
- Each box wall also has a label, such as guzheng or fan. If the object in the box is the same as the label on the box wall (for example, if the box contains guzheng, the label is also guzheng), then the object in the box is real and of good quality. Getting this box (no matter what is inside) will make people happy.
- If the object in the box is different from the label on the box wall (for example, if the box contains guzheng, but the label is fan), then the object in the box is fake and of bad quality. Getting this box (no matter what is inside) will make people sad.
- In the story, there is a boy named Xiaoming. He sometimes opened his box, sometimes didn’t open his box. The test sentence describes the box that Xiaoming got.
- You need to choose which of A, B, C, D matches Xiaoming’s box.

Likan Zhan, 2018-12-16
你首先会看到两个物体，如古筝和扇子。然后会看到一张测试图片。
每张测试图片中都有四个箱子，其中三个是开着的，一个是关着的。当箱子关着的时候，我们不知道里面的物体是什么。但是箱子无论打开与否，里面都装着前述两个物体中的一个，如古筝或扇子。
每个箱子壁上还都贴着一个商标，如古筝或扇子。如果箱子里的物体和箱子壁上的商标一样（如箱子里是古筝，箱子壁上的商标也是古筝），那么箱子里的物体就货真价实，质量就好。得到这个箱子（无论箱子里是什么）的人就会很高兴。
如果箱子里的物体和箱子壁上的物体不一样（如箱子里是古筝，而箱子壁上的商标是扇子），那么箱子里的物体就是假冒伪劣，质量很差。得到这个箱子（无论箱子里是什么）的人就很伤心。
故事中，有个叫小明的男孩得到了其中一个箱子。小明有时候已经打开了自己的箱子，有时候还没打开自己的箱子。测试句描述的就是小明拿到的这个特定的箱子。
你要根据听到的测试句按键选择小明拿到的这个箱子是A、B、C、D中的哪个。
The case of conditionals

- 你首先会看到两个物体，如古筝和扇子。然后会看到一张测试图片。
- 每张测试图片中都有四个箱子，其中三个是开着的，一个是关着的。当箱子关着的时候，我们不知道里面的物体是什么。但是箱子无论打开与否，里面都装着前述两个物体中的一个，如古筝或扇子。
- 每个箱子壁上还都贴着一个商标，如古筝或扇子。如果箱子里的物体和箱子壁上的商标一样（如箱子里是古筝，箱子壁上的商标也是古筝），那么箱子里的物体就货真价实，质量就好。得到这个箱子（无论箱子里是什么）的人就会很高兴。
- 如果箱子里的物体和箱子壁上的物体不一样（如箱子里是古筝，而箱子壁上的商标是扇子），那么箱子里的物体就是假冒伪劣，质量很差。得到这个箱子（无论箱子里是什么）的人就很伤心。
The case of conditionals

- You first see two objects, like a zither and a fan. Then you see a test picture.
- Each test picture contains four boxes, three of which are open, and one is closed. When the box is closed, we don’t know what object is inside. However, whether the box is open or closed, there is always one of the two objects inside, like a zither or a fan.
- Each box has a sticker, like a zither or a fan. If the object inside the box and the sticker match (like the box contains a zither and the sticker is also a zither), then the object inside is genuine, and the quality is good. Anyone getting this box (regardless of what is inside) will be very happy.
- If the object inside the box and the sticker don’t match (like the box contains a zither, but the sticker is a fan), then the object inside is fake, and the quality is very poor. Anyone getting this box (regardless of what is inside) will be very sad.
- In the story, there is a boy named Xiaoming who got one of these boxes. Xiaoming sometimes opened his box, and sometimes didn’t. The test sentence describes the specific box Xiaoming got.
The case of conditionals

- You first see two objects, such as a zither and a fan. Then you see a test image.
- Each test image contains four boxes, among which three are opened and one is closed. When the box is closed, we don’t know what object is inside. However, the box is always opened or closed, and it always contains one of the two objects, such as a zither or a fan.
- Each box is also attached to a label, such as a zither or a fan. If the object inside the box and the label on the box are the same (such as both a zither inside and a zither label), then the box contains a genuine object, and its quality is good. The owner of this box (no matter what is inside) would be very happy.
- If the box contains an object and the label on the box are different (such as a zither inside and a fan label), then the box contains a fake object, and its quality is poor. The owner of this box (no matter what is inside) would be very sad.
- In the story, a boy named Xiaoming got one of these boxes. Sometimes Xiaoming has opened his box, and sometimes he hasn’t. The test sentence describes the specific box that Xiaoming got.
- You need to choose which box among A, B, C, D is the one Xiaoming got, according to the heard test sentence.
The case of conditionals

A

B

C

D
a). **Because**  

Because the box contains a fan/zither, therefore Xiaoming is very happy/*sad.

b). **If**  

If the box contains a fan/zither, then Xiaoming will be very happy/sad.
Visual World Paradigm: An eye-tracking technique

(Zhan, 2018b)
The case of conditionals

Sentential Connectives

Counts of Chosen Boxes

Because | If

Different
- 98.4%
- 51.9%
- 4.4%

Same
- 95.6%
- 12.5%
- 83.5%

Happy

Sad

Chosen Box
- Same_Same (Box A)
- Same_Different (Box B)
- Different_Different (Box C)
- Closed_Same (Box D)
The case of conditionals

![Graphs showing the proportion of fixations over temporal positions for different conditionals (Same_Different, Same_Same, Closed_Same, Different_Different). The graphs compare fixations for 'If' and 'Because' connectives.](image-url)
The case of disjunctions

Return to the two atomic propositions: A, B

The conditional statement: If not-A, then B

Is logically equivalent to: A or B
The case of disjunctions

- Return to the two atomic propositions:
  \[ A, B \]
The case of disjunctions

- Return to the two atomic propositions: $A, B$

- The conditional statement:

  If not-$A$, then $B$
The case of disjunctions

- Return to the two atomic propositions: 
  \( A, B \)

- The conditional statement:
  \[ \text{If not-}A, \text{ then } B \]

- Is logically equivalent to:
  \( A \text{ or } B \)
The case of disjunctions
The case of disjunctions

- 首先你会顺序看到两个动物，如母鸡、狐狸。然后你会看到一个黑点，你要用眼睛盯着这个黑点的同时按一下空格键。
The case of disjunctions

- First, you will sequentially see two animals, such as a hen and a fox. Then you will see a black dot, and you need to focus your eyes on this black dot while pressing the space bar.
- Then you will see four boxes, of different sizes and open or closed. Each large box contains two of the animals you've seen, and these two animals are different, such as hen and fox; each small box contains one of the animals you've seen, sometimes hen, sometimes fox. Each box contains what animal is unrelated to what is in other boxes. Each box contains what animal is unrelated to whether the box is open or closed.
- Finally, you will hear a test sentence. Your task is to quickly determine which box is Xiao Ming's, and press the corresponding key (the labeled ABCD keys on the keyboard). If there are two or more options that are suitable, please choose the most suitable one. If there are no suitable options, please randomly select one.
The case of disjunctions

- First, you will see two animals in sequence, such as a hen and a fox. Then, you will see a black dot, and you must focus on this dot while pressing the space bar.

- Then, you will see four boxes, some large and some small, some open and some closed. Each large box contains two animals that you have seen before, and these two animals are different, such as a hen and a fox; each small box contains one of the two animals you have seen before, sometimes a hen, sometimes a fox. Each box contains what animals are unrelated to each other, and each box is open or closed is unrelated.

- Finally, you will hear a test sentence. Your task is to find the box that is Xiao Ming's as soon as possible and choose the corresponding key (the key labeled A B C D on the keyboard). If there are two or more options that are suitable, choose the most suitable one. If there are no suitable options, choose randomly.
The case of disjunctions

A

B

C

D

(Zhan, 2018a, 2018b)
The case of disjunctions

A

B

C

D

(Zhan, 2018a, 2018b)
The case of disjunctions

a. And

Xiaoming’s box contains a cow and a rooster.

b. But

Xiaoming’s box contains a cow but not a rooster.

c. Or

Xiaoming’s box contains a cow or a rooster.

(Zhan, 2018a, 2018b)
The case of disjunctions

Counts of Responses

Sentential Connectives

Chosen Box

Conjunction (S1 and S2)

But (S1 but not S2)

Disjunction (S1 or S2)

Box A (big open)

Box B (small closed)

Box C (second mentioned)

Box D (first mentioned)

(Zhan, 2018a, 2018b)
The case of disjunctions

Sentential Connective: Conjunction (S1 and S2), But (S1 but not S2), Disjunction (S1 or S2)

(Zhan, 2018a, 2018b)
The case of negation

• Given a set of atomic propositions: A, B, C,
• The negated statement: Not A
• Is roughly equivalent to: B or C or
The case of negation

- Given a set of atomic propositions:
  
  A, B, C, …
The case of negation

- Given a set of atomic propositions:
  \[ A, B, C, \ldots \]

- The negated statement:
  \[ \neg A \]
The case of negation

- Given a set of atomic propositions:
  \[ A, B, C, \ldots \]
- The negated statement:
  \[ \text{Not } A \]
- Is roughly equivalent to:
  \[ B \text{ or } C \text{ or } \ldots \]
The case of negation

A

B

C

D
The case of negation
The case of negation

a. But

小明的箱子里有 一只 奶牛 但 没有 公鸡
Xiaoming's box in have one-CL cow but not rooster

Xiaoming's box contains a cow but not a rooster.

b. Not

小明的箱子里没有 一只 公鸡 但 有只 奶牛
Xiaoming's box in not have one-CL rooster but has-CL cow

Xiaoming's box doesn't contain a rooster but a cow.
The case of negation

But (S1 but not S2) Not (Not S1 but S2)

Counts of Responses
Chosen Box
Box A (big open) Box B (small closed) Box C (second mentioned) Box D (first mentioned)

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The case of negation

Box A (big open)

Box B (small closed)

Box C (second mentioned)

Box D (first mentioned)

Proportions of fixations

Sentential Connective

S1 but not S2
Not S2 but S1

Likan Zhan, 2018-12-16
The case of epistemic modality
The case of epistemic modality

- Conditional, Disjunction, and Negation all involve Modality.
The case of epistemic modality

- Conditional, Disjunction, and Negation all involve Modality.
- But, wait, what about the epistemic modals themselves?

*Might, Must*
The case of epistemic modality
The case of epistemic modality

a. Be

小明的箱子里有一只奶牛
Xiaoming's box in have one-CL cow

There might be a cow in Xiaoming's box.

b. Might

小明的箱子里也许有一只奶牛
Xiaoming's box in might have one-CL cow

There might be a cow in Xiaoming's box.

c. Must

小明的箱子里一定有一只奶牛
Xiaoming's box in must have one-CL cow

There must be a cow in Xiaoming's box.
The case of epistemic modality

Counts of Responses

Chosen Box

Box A (big open)  Box B (small closed)  Box C (second mentioned)  Box D (first mentioned)

Likan Zhan, 2018-12-16
The case of epistemic modality

Box A (big open)  Box B (small closed)
Box C (big closed) Box D (first mentioned)

Proportions of fixations

Sentential Connective: Be, Might, Must

Time (Seconds)

Likan Zhan, 2018-12-16
Outstanding questions

• Is modality an essential property in reasoning, especially in deductive reasoning?
• Is modality important in language itself?
• What are the neural mechanisms underlying the modal processes?
• Can these observations be generalized to other reasoning processes?
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- Is modality important in language itself?
- What are the neural mechanism underling the modal processes?
- Can these observations be generalized to other reasoning processes?
The End
References


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