A LOGIC FRAMEWORK FOR CONFORMANT PLANNING

Yanjing Wang
Department of Philosophy, Peking University
(Based on joint works with Yanjun Li and Quan Yu)
Delta workshop, Fudan University, Dec. 5th 2015
Conformant planning

Ideas from philosophical logic

A logic framework
CONFORMANT PLANNING
LOST WITH A MAP AT HAND
LOST WITH A MAP AT HAND

You are here

You Are Here

You Are Here
A rookie spy sneaking in an enemy building was guided by his headquarters. The communication with the HQ was lost at some point. Now someone spotted him and pulled the alarm. In panic he got lost...

Suppose $s_3$ is actually where he is.

What should he do now to be safe as quickly as possible?
Following plans can all *in fact* lead the agent to a safe place:

1. Moving right (*r*): the agent may not know that he is safe afterwards.
2. Moving up (*u*): the agent may know that he is safe afterwards, but he couldn’t have known it beforehand.
3. Moving right and up (*ru*): the agent knows that it will guarantee his safety even before executing it.

Plans 1 and 2 are good if the planner is the HQ. Plan 3 is good for the agent as the planner.
The goal of AI planning:

**Uncertain or false** \( \rightarrow \) **Certain and true**

Sources of uncertainty: initial states, observation power, non-deterministic actions

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Init</th>
<th>Obs</th>
<th>Act</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical</td>
<td>no</td>
<td>full</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>FOND</td>
<td>no</td>
<td>full</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>MDP</td>
<td>no</td>
<td>full</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Conformant</td>
<td>yes</td>
<td>none</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Contingent</td>
<td>yes</td>
<td>partial</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>POMDP</td>
<td>yes</td>
<td>partial</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
The goal of planning:

！

Uncertain or false → Certain and true

Sources of uncertainty: initial states, observation power, non-deterministic actions

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Init</th>
<th>Obs</th>
<th>Act</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical</td>
<td>no</td>
<td>full</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>FOND</td>
<td>no</td>
<td>full</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>MDP</td>
<td>no</td>
<td>full</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Conformant</td>
<td>yes</td>
<td>none</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Contingent</td>
<td>yes</td>
<td>partial</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>POMDP</td>
<td>yes</td>
<td>partial</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
CLASSICAL VS. CONFORMANT PLANNING

• Classical planning: given one red to reach some blue by a sequence of actions, i.e., reachability over deterministic labelled transition systems. E.g., $rr$ is a good plan.

  S_1 \rightarrow r \rightarrow S_2 \rightarrow r \rightarrow S_3 \rightarrow r \rightarrow S_4 \rightarrow r \rightarrow S_5

• Conformant planning: given a set of reds by an action sequence that can always work no matter where to start: executable and reaching some blue when finish. E.g., $ru$ is a good conformant plan but neither $u$ nor $r$ is good.

  S_1 \rightarrow r \rightarrow S_2 \rightarrow r \rightarrow S_3 \rightarrow r \rightarrow S_4 \rightarrow r \rightarrow S_5
IDEAS FROM PHILOSOPHICAL LOGIC
Important features in conformant planning:

- initial uncertainty
- uncertainty tracking after actions

Corresponding notions formalized in philosophical logic:

- knowledge
- knowledge updates after actions

Conformant planning: given what you know initially find a plan such that you know it will always reach your goal.
Epistemic Logic (von Wright, Hintikka):

- Language: “agent \( i \) knows that \( \phi \)” \((K_i\phi)\).
- Model: “possible worlds” with indistinguishability relations
- Semantics: you know that \( \phi \) iff you can rule out all the \( \neg\phi \) possibilities

\[ M, s \models p \land \neg Kp \]
S5 SYSTEM (STRONGEST EPISTEMIC LOGIC)

System S5

**Axioms**

- **TAUT** all the instances of tautologies
- **DISTK** $K_i(p \rightarrow q) \rightarrow (K_ip \rightarrow K_iq)$
- **T** $K_i p \rightarrow p$
- **4** $K_ip \rightarrow K_iK_ip$
- **5** $\neg K_ip \rightarrow K_i\neg K_ip$

**Rules**

- **MP** $\frac{\phi, \phi \rightarrow \psi}{\psi}$
- **NECK** $\frac{\phi}{K_i\phi}$
- **SUB** $\frac{\phi}{\phi[p/\psi]}$

4 and 5 axioms in Confucius’ teaching:

知之为知之，不知为不知，是知也
Two modal logic approaches handling knowledge and actions:

- **Epistemic Temporal Logic (ETL):** knowledge in distributed systems based on *temporal logic*. [FHMV95, PR85]

- **Dynamic Epistemic Logic (DEL):** knowledge in multi-agent interactions based on *epistemic logic*. [Pla89, GG97, BMS98, vDvdHK07]
<table>
<thead>
<tr>
<th>language</th>
<th>model</th>
<th>semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>time+K</td>
<td>temporal+epistemic</td>
</tr>
<tr>
<td>DEL</td>
<td>K+action</td>
<td>epistemic</td>
</tr>
</tbody>
</table>

\[
\neg Kp \land F Kp
\]
\[
\neg Kp \land [!p]Kp
\]

Dynamic semantics: the **meaning** of an action is the *change* it brings to the knowledge states of the agents. (dates back to Stalnaker, Groenendijk, Stokhof and Veltman).
We may not construct the temporal structure from scratch.

<table>
<thead>
<tr>
<th>language</th>
<th>model</th>
<th>semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>time+K</td>
<td>temporal+epistemic</td>
</tr>
<tr>
<td>DEL</td>
<td>K+action</td>
<td>epistemic</td>
</tr>
<tr>
<td>Mixed</td>
<td>action+K</td>
<td>temporal+epistemic</td>
</tr>
</tbody>
</table>

Such a logic usually cannot be reduced to epistemic logic, but techniques developed in [WC13, WA13] give a general method to axiomatize DEL-like logics without reductions.
A LOGIC FRAMEWORK
Given a set $P$ of basic propositions and a non-empty set $A$ of basic actions, an uncertainty map (UM):

$$\mathcal{M} = \langle S, \{R_a \mid a \in A\}, V, U \rangle$$

where $\langle S, \{R_a \mid a \in A\}, V \rangle$ is a Kripke model, and $\emptyset \subset U \subseteq S$. $\mathcal{M}, s$ is a pointed UM model, if $s \in U$.

**Example** $(\mathcal{M}, s_3)$

\[ S_7 \leftarrow l \rightarrow S_6 \quad \stackrel{u}{\uparrow} \quad S_8: \text{Safe} \quad \stackrel{u}{\uparrow} \quad S_9: \text{Safe} \]

\[ S_1 \quad \stackrel{r}{\rightarrow} \quad S_2 \quad \stackrel{r}{\rightarrow} \quad S_3 \quad \stackrel{r}{\rightarrow} \quad S_4: \text{Safe} \quad \rightarrow r \rightarrow S_5 \]
• **EAL** language with action and knowledge as modalities:

\[ \phi ::= \top | p | \neg \phi | (\phi \land \phi) | \langle a \rangle \phi | K\phi \]

where \( p \in P, a \in A \).

• For abbreviations: \( \bot ::= \neg \top, \phi \lor \psi ::= \neg (\neg \phi \land \neg \psi), \phi \rightarrow \psi ::= \neg \phi \lor \psi, [a]\phi ::= \neg \langle a \rangle \neg \phi, \hat{K} \phi ::= \neg K \neg \phi \).

• \( K\phi \) says that the agent knows that \( \phi \).

• \( \langle a \rangle \phi \) says that there exists an execution of \( a \) which will make \( \phi \) true.
Given any UM model $\mathcal{M} = \langle S, \{R_a \mid a \in A\}, V, U \rangle$, the satisfaction relation on pointed UM model $\mathcal{M}$, $s$ is defined as:

$$\mathcal{M}, s \models K\phi \iff \forall u \in U : \mathcal{M}, u \models \phi$$

$$\mathcal{M}, s \models \langle a \rangle \phi \iff \exists t \in S \text{ such that } s \xrightarrow{a} t \text{ and } \mathcal{M}^a, t \models \phi$$

where

- $\mathcal{M}^a = \langle S, \{R_a \mid a \in A\}, V, U^a \rangle$
- $U^a = \{r' \mid \exists r \in U \text{ such that } r \xrightarrow{a} r'\}$: ‘carry the bubble’ further along $a$ transitions.
The truth value of **EAL** formulas is *not* defined on every state and it is “path dependent”:

Let the left-hand-side model be $\mathcal{M}$ then:

$\mathcal{M}^b, s_3 \models Kp$ but $\mathcal{M}^{aa}, s_3 \not\models Kp$ thus $\mathcal{M}, s_1 \models \langle b \rangle Kp \land \langle a \rangle \langle a \rangle \neg Kp$. 

27
• Normal form: $K$ can be pushed outside $\langle a \rangle$
• A bisimulation notion
• Finite model property
• A sound and complete axiomatization
Rules:
MP    NECK    NEC(a)    SUB

Axioms:
TAUT    all the axioms of propositional logic
DISTK   \[ K(p \rightarrow q) \rightarrow (Kp \rightarrow Kq) \]
DIST(a) \[ [a](p \rightarrow q) \rightarrow ([a]p \rightarrow [a]q) \]
T       \[ Kp \rightarrow p \]
4       \[ Kp \rightarrow KKp \]
5       \[ \neg Kp \rightarrow K\neg Kp \]
PR(a)   \[ K[a]p \rightarrow [a]Kp \]
NL(a)   \[ \langle a\rangle Kp \rightarrow K[a]p \]
• Model: compact (Kripke model with a bubble)
• Language: simple (K and ⟨a⟩)
• Semantics: Kripke and dynamic
• Useful in knowledge tracking and plan verification?
Definition

Given $\mathcal{M} = \langle S, \{R_a | a \in A\}, V, U \rangle$ and a set $\emptyset \subset G \subseteq S$, find a sequence $a_1, \ldots, a_n$ such that $a_1, \ldots, a_n$ is strongly executable and $U|^{a_1,\ldots,a_n} \subseteq G$. Strongly executable means for each $u \in U \mathcal{M}, u \models (\langle a_1 \rangle \cdots \langle a_n \rangle) \top$ where $\langle a \rangle \phi$ is the shorthand of $[a] \phi \land \langle a \rangle \phi$.

```
s_1 : p
\downarrow
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
\_ \_ \_ \_ \_ \_ \_
```

$ab$ is not strongly executable in the above model.
In practice, \( G \) is often given by a Boolean formula \( \phi \), and a set of actions that you can use is limited to some \( B \subseteq A \).

**Definition (Conformant planning)**

Given an uncertainty map \( \mathcal{M} \), a goal formula \( \phi \), and a set \( B \subseteq A \), the conformant planning problem is to find a finite (possibly empty) sequence \( \sigma = a_1 a_2 \cdots a_n \in B^* \) such that for each \( u \in U_\mathcal{M} \) we have \( \mathcal{M}, u \models (a_1) (a_2) \cdots (a_n) \phi \), i.e., \( \mathcal{M}, u \models K(a_1) (a_2) \cdots (a_n) \phi \) for some \( u \in U \). The existence problem of conformant planning is to test whether such a sequence exists.
Intuitively, we want a plan which will never fail w.r.t. non-deterministic actions and initial uncertainty of the agent. E.g., \( ru \) is a conformant plan to the agent.

\[
\begin{align*}
S_7 & \leftarrow l \rightarrow S_6 & \text{S8: Safe} & \text{S9: Safe} \\
& \uparrow & \uparrow & \uparrow \\
& u & u & u \\
S_1 \quad \rightarrow & S_2 \quad \rightarrow & S_3 \quad \rightarrow & S_4: \text{ Safe} \rightarrow r \rightarrow S_5
\end{align*}
\]

\[ \mathcal{M}, s_3 \models K(r) (\downarrow u) \text{ Safe} \land K(r) (\downarrow u) K\text{ Safe} \]

We can **verify** conformant plans by model checking **EAL**. What about checking the existence of a plan?
To Express the Existence of a Conformant Plan

Enriched language EPDL

\[ \phi ::= \top | \rho | \neg \phi | \phi \land \phi | [\pi]\phi | K\phi \]
\[ \pi ::= a | ?\phi | \pi; \pi | \pi \cup \pi | \pi^* \]

E.g., EPDL can express \( K[(?\neg Kp; a)^*; ?Kp; b]K[c]q \)

| \( \mathcal{M}, s \models [\pi]\phi \) | \( \iff \) | for all \( \mathcal{M}', s' : (\mathcal{M}, s)[\pi](\mathcal{M}', s') \) implies \( \mathcal{M}', s' \models \phi \) |
|-------------------------------------------------|
| \( (\mathcal{M}, s)[a](\mathcal{M}', s') \) | \( \iff \) | \( \mathcal{M}' = \mathcal{M}|^a \) and \( s \xrightarrow{a} s' \) |
| \( (\mathcal{M}, s)[?\psi](\mathcal{M}', s') \) | \( \iff \) | \( (\mathcal{M}', s') = (\mathcal{M}, s) \) and \( \mathcal{M}, s \models \psi \) |
| \( (\mathcal{M}, s)[\pi_1; \pi_2](\mathcal{M}', s') \) | \( \iff \) | \( (\mathcal{M}, s)[\pi_1] \circ [\pi_2](\mathcal{M}', s') \) |
| \( (\mathcal{M}, s)[\pi_1 + \pi_2](\mathcal{M}', s') \) | \( \iff \) | \( (\mathcal{M}, s)[\pi_1] \cup [\pi_2](\mathcal{M}', s') \) |
| \( (\mathcal{M}, s)[\pi^*](\mathcal{M}', s') \) | \( \iff \) | \( (\mathcal{M}, s)[\pi]^* (\mathcal{M}', s') \) |
Recall: a conformant plan requires that for each \( u \in U_M \) we have \( M, u \models \langle a_1 \rangle \langle a_2 \rangle \cdots \langle a_n \rangle \phi \).

**Proposition**

There exists a conformant plan w.r.t. \( B \subseteq A \) and a Boolean \( \phi \) on \( M, s \) iff \( M, s \models \langle (\Sigma_{a \in B}(?K\langle a \rangle T; a))^* \rangle K\phi \).

Call the formula \( \theta_{B,\phi} \). If \( B = \{a_1, a_2\} \) then

\[
\theta_{B,\phi} = \langle (\langle ?K\langle a_1 \rangle T; a_1 \rangle + \langle ?K\langle a_2 \rangle T; a_2 \rangle)^* \rangle K\phi.
\]
What about $K((\Sigma B)^*) \phi$?

**Example**

Let $U = \{s_1, s_2\}$, uncertainty map $M = \langle \mathcal{N}, U \rangle$ and the goal formula is $p$. Let $B = \{a, b\}$, we have $M, s_1 \models K(\Sigma B^*) p$, but there is no solution to this conformant planning problem.

```
\[ \begin{align*}
S_1 & \xrightarrow{a} S_3 \xrightarrow{b} S_5 : p \\
S_2 & \xrightarrow{b} S_4 \xrightarrow{a} S_6 : p
\end{align*} \]
```
What about $\langle (\Sigma_{a \in B}(?K\langle a \rangle T; a))^* \rangle \phi$?

**Example**

Let $U = \{s_1\}$, and let the goal formula be $p$. As we can see, there is no solution to this conformant planning problem. Indeed $M, s_1 \not\models \langle (\Sigma_{a \in B}(?K\langle a \rangle T; a))^* \rangle Kp$ with $B = \{a, b\}$, but we could have $M, s_1 \models \langle (\Sigma_{a \in B}(?K\langle a \rangle T; a))^* \rangle p$.

\[ S_1 \xrightarrow{a} S_2 \xrightarrow{b} S_5 : p \]

$S_4$
Definition (Generalized conformant planning)

Given an uncertainty map $\mathcal{M}$, a goal formula $\phi \in \text{EPDL}$, and a test-free (i.e., $\forall \phi$-free) $\pi \in \Pi_A$, the generalized conformant planning problem is to find a finite (possibly empty) sequence $\sigma = a_1 \cdots a_n \in \mathcal{L}(\pi)$ such that for some $u \in U\mathcal{M}, \mathcal{M}, u \models K\langle a_1 \rangle \cdots \langle a_n \rangle \phi$. The existence problem of conformant planning is to test whether such a sequence exists.

Generalizations: goal formula and plan constraint
Take $p$ as the relief of a pain, and take $q$ as some side effect of medicines $a$ and $b$. If the goal is $p$ then both $a$ and $b$ are conformant plans. If the goal is $p \land \neg Kq$, only $a$ is a good plan.

\[
\begin{align*}
S_1 & \xrightarrow{a} S_3 : p \\
S_2 & \xrightarrow{a} S_4 : p, q \\
S_4 & \xrightarrow{b} S_5 : p, q
\end{align*}
\]
Let $p$ express that a tooth hurts. You can either replace it with a false tooth ($a$) or fix the problem temporarily without the replacement ($b$). The trouble for the second option is that it may go wrong again in some time ($t$). What would you choose? If your goal is $[t^*] \neg p$, which means free of worries forever, then $a$ is clearly a better plan.

![Diagram]

**Diagram**

- $s_1 : p$
- $a \rightarrow s_2$
- $b \rightarrow s_3$
- $t$
There are two kinds of transportation on the way to $p$: by bus ($a$) or by walking ($b$). However, you can afford taking a bus only one time. Therefore, the solution should be a sequence allowed by $\pi = b^* ; a ; b^* + b^*$. It is easy to see that under this constraint only $a ; b$ is a plan.

$$\{ S_1 \}_{a} \Rightarrow S_2 \stackrel{a}{\Rightarrow} S_3 : p$$
Let $t$ be the translation of test-free programs such that each atomic action $a$ is replaced by $(?K\langle a\rangle \top; a)$:

\[
\begin{align*}
t(a) &= (?K\langle a\rangle \top; a) \\
t(\pi; \pi') &= t(\pi); t(\pi') \\
t(\pi + \pi') &= t(\pi) + t(\pi') \\
t(\pi^*) &= (t(\pi))^*
\end{align*}
\]

**Proposition**

*There exists a conformant plan w.r.t. a test-free $\pi \in \Pi_A$ and a $\phi \in \text{EPDL}$ on $\mathcal{M}$, $s$ iff $\mathcal{M}, s \models \langle t(\pi) \rangle K\phi$.*

The standard conformant planning is under constraint $\pi = (\Sigma B)^*$. 
Theorem

Model checking EPDL is PSPACE-complete.

The same as standard conformant planning on labelled transition systems. Get more for free!

Usual global model checking algorithm by labelling is not applicable since the semantics of $K$ is path dependent.
Given a QBF $\alpha_n = Q_1x_1Q_2x_2 \ldots Q_nx_n\phi(x_1, \ldots, x_n)$, the formula $\theta_{\alpha_n}$ is defined as

$$QT_1 \cdots QT_n \psi(\hat{K}p_1, \ldots, \hat{K}p_n, \hat{K}q_1, \ldots, \hat{K}q_n)$$

where $QT_i$ is $\langle (a_i + \bar{a}_i); ?(p_i \lor q_i) \rangle$ if $i$ is odd and $QT_i$ is $[(a_i + \bar{a}_i); ?(p_i \lor q_i)]$ if $i$ is even, and $\psi$ is obtained from $\phi(x_1, \ldots, x_n)$ by replacing each $x_i$ with $\hat{K}p_i$ and $\neg x_i$ with $\hat{K}q_i$.

We can show that $\alpha$ is true iff $\mathcal{M}_n, x_0 \models \theta_{\alpha}$
Given any Kripke model $\mathcal{N} = \langle S, \{R_a \mid a \in A\}, \mathcal{V} \rangle$, we define the ETS model $\mathcal{N}^\bullet$ as follows:

$$
\begin{align*}
S^\bullet &= \{s_\Gamma \mid s \in S, \Gamma \in 2^S, s \in \Gamma\} \\
R^\bullet_a &= \{(s_\Gamma, t_\Delta) \mid s \xrightarrow{a} t, \Delta = \Gamma|^{a}\} \\
\sim^\bullet &= \{(s_\Gamma, t_\Delta) \mid \Gamma = \Delta\} \\
\mathcal{V}^\bullet(s_\Gamma) &= \mathcal{V}(s)
\end{align*}
$$

where $\Gamma|^{a} = \{t \in S \mid \exists s \in \Gamma \text{ such that } s \xrightarrow{a} t\}$. 
Given any ETS model $\mathcal{M} = \langle \mathcal{S}, \{R_a \mid a \in A\}, \sim, \mathcal{V} \rangle$ and any state $s \in \mathcal{S}$, the satisfaction relation for EPDL formulas is defined as follows (the Boolean cases are as in the standard modal logic):

<table>
<thead>
<tr>
<th>Formula</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{M}, s \models K\phi$</td>
<td>$\forall u \in \mathcal{S} : s \sim u$ implies $\mathcal{M}, u \models \phi$</td>
</tr>
<tr>
<td>$\mathcal{M}, s \models [\pi]\phi$</td>
<td>$\forall t \in \mathcal{S} : s \xrightarrow{\pi} t$ implies $\mathcal{M}, t \models \phi$</td>
</tr>
<tr>
<td>$\xrightarrow{a}$</td>
<td>$= R_a$</td>
</tr>
<tr>
<td>$?\phi$</td>
<td>$= {(s, s) \mid \mathcal{M}, s \models \phi}$</td>
</tr>
<tr>
<td>$\pi_1 ; \pi_2$</td>
<td>$= \xrightarrow{\pi_1} \circ \xrightarrow{\pi_2}$</td>
</tr>
<tr>
<td>$\pi_1 + \pi_2$</td>
<td>$= \xrightarrow{\pi_1} \cup \xrightarrow{\pi_2}$</td>
</tr>
<tr>
<td>$\pi^*$</td>
<td>$= (\xrightarrow{\pi})^*$</td>
</tr>
</tbody>
</table>

where $\circ, \cup, \ast$ at right-hand side denote the usual composition, union and reflexive transitive closure of binary relations respectively.
Proposition

Given any Kripke model $\mathcal{N}$, we have

(i) $((\mathcal{N}, \Gamma), s)[\pi]((\mathcal{N}, \Delta), t)$ iff $s_\Gamma \xrightarrow{\pi} t_\Delta$ in $\mathcal{N}^\bullet$;
(ii) $(\mathcal{N}, \Gamma), s \models \phi$ iff $\mathcal{N}^\bullet, s_\Gamma \models \phi$.

Proposition

Model checking EPDL can be done in PSPACE.

The trick is for space complexity you don’t need to compute the $\mathcal{N}^\bullet$ in advance!
ADVANTAGES OF SUCH A LOGICAL APPROACH

• much more general with the same computational price!
• natural specification of goals and constrains on plans
• specification and verification of plans with (epistemic) conditions and loops
• abstraction, refinement and equivalence of the plans
• (in principle) probability may be plugged in
• to compare complexity of different planning problems as MC of fragments over various classes of models

You have a conformant plan for $\phi \approx$ you know how to guarantee $\phi$. It inspired a logic of knowing how (Wang 15).
• Complexity of satisfiability of EPDL (decidability shown by Li 15)
• Axiomatization of EPDL
• Contingent planning
• Probabilistic planning
• Multi-agent
• Incomplete map
BACK TO THE THEME OF THIS WORKSHOP

- Mathematics
- LOGIC
- Computer Science
- Philosophy
From Sicun Gao:

Logicians always want to be:

- Mathematicians of mathematicians
- Computer scientists of computer scientists
- Philosophers of philosophers

However, they often end up being:

- Mathematicians to philosophers
- Philosophers to computer scientists
- Computer scientists to mathematicians
• Mathematics: Rigorous
• Computer science: Computable
• Philosophy: To the point

Logicians may have them all!
Thank you for your attention!
小心地滑
Slip carefully
Guillaume Aucher and Thomas Bolander.  
Undecidability in epistemic planning.  

Mikkel Birkegaard Andersen, Thomas Bolander, and Martin Holm Jensen.  
Conditional epistemic planning.  

Guillaume Aucher.  
Del-sequents for regression and epistemic planning.  

Thomas Bolander and Mikkel Birkegaard Andersen.
Epistemic planning for single and multi-agent systems. 

A. Baltag, L. Moss, and S Solecki. 
The logic of public announcements, common knowledge, and private suspicions. 

R. Fagin, J. Halpern, Y. Moses, and M. Vardi. 
*Reasoning about knowledge*. 

Liangda Fang and Yongmei Liu. 
Multiagent knowledge and belief change in the situation calculus.
J. Gerbrandy and W. Groeneveld. 
**Reasoning about information change.**

Martin Holm Jensen. 
**Planning using dynamic epistemic logic: Correspondence and complexity.**

Benedikt Löwe, Eric Pacuit, and Andreas Witzel.
DEL planning and some tractable cases.

Jérôme Lang and Bruno Zanuttini.
Knowledge-based programs as plans - the complexity of plan verification.

Rajdeep Niyogi and Ramaswamy Ramanujam.
An epistemic logic for planning with trials.
Héctor Palacios and Hector Geffner.  
From conformant into classical planning: Efficient translations that may be complete too.  

J. A. Plaza.  
Logics of public communications.  

R. Parikh and R. Ramanujam.  
Distributed processes and the logic of knowledge.


Yanjing Wang and Qinxiang Cao.  
**On axiomatizations of public announcement logic.**  

Yanjing Wang and Yanjun Li.  
**Not all those who wander are lost: Dynamic epistemic reasoning in navigation.**  

Quan Yu, Yanjun Li, and Yanjing Wang.  
**A dynamic epistemic framework for conformant planning.**

Quan Yu, Ximing Wen, and Yongmei Liu. 
**Multi-agent epistemic explanatory diagnosis via reasoning about actions.**