Dynamically Generated Commitment Protocols

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Motivation[1]

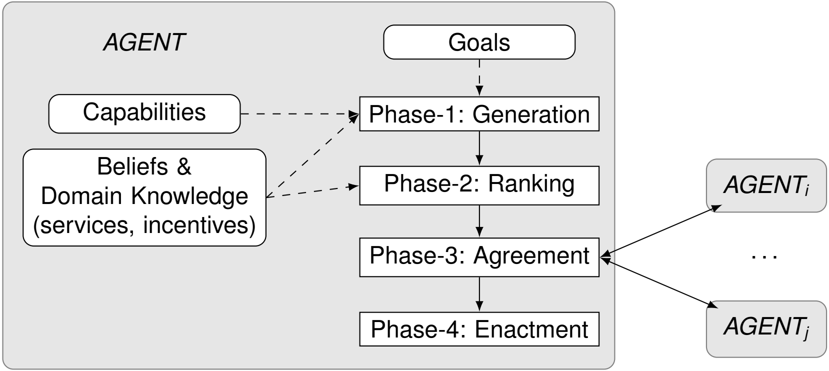
- Design-time protocol development:
  - Pro: Easier design and development of the system
  - Pro: Allows verification of correctness
  - Con: Limits functionality of agents
  - Con: Hard to adapt to new situations in open systems
- *Alternative: Agents create their own protocol at run-time according to their own requirements.*

[1] Akın Günay, Michael Winikoff, and Pınar Yolum. “Dynamically generated commitment protocols in open systems”. In: *Autonomous Agents and Multi-Agent Systems* 29.2 (2015), pp. 192–229.

Challenges

- How to automate creation of protocols?
- How to define criteria to guide protocol creation?
- How to evaluate the created protocols?
- Efficiency and scalability of protocol creation and evaluation.

Agent Framework



Formalizing agent (1)

Definition (Agent)

An *agent* is a three tuple $\langle \mathcal{G}, \mathcal{A}, \mathcal{B} \rangle$, where $\mathcal{G}$ is the agent's goals, $\mathcal{A}$ is the agent's abilities and $\mathcal{B}$ is the agent's beliefs.

Definition (Goal)

$G_x(r)$ denotes the *goal* of agent x to bring about the proposition r.

Definition (Ability)

$A_x(d, r)$ denotes the *ability* of agent x to bring about the proposition r, if the precondition d holds.

Formalizing agent (2)

Definition (Belief)

$S_x(y, d, r)$ denotes that the agent x believes that the agent y can provide a service to bring about the proposition r, if the precondition d holds. $I_x(y, w, r)$ denotes that the agent x believes that the agent y accepts the proposition w as an incentive for its services to bring about r.

Definition (Commitment)

$C(x, y, d, r)$ denotes the *commitment* of the debtor agent x to the creditor agent y to bring about the consequent r if the antecedent d holds.

Definition (Commitment Protocol)

A *commitment protocol* p is a set of commitments.

Phase-1: Generation (Informal)

- Objective: to create a set of candidate protocols that *support* the generator agent's goals
- Inputs: goals, capabilities, services, incentives

Goal Support

A goal p of agent x is *supported* by a protocol if:

Case-1: x can achieve p using its own capabilities

Case-2:
- $C(y, x, q, p)$ is involved in the protocol,
- p can be achieved by using a service of y,
- q is required for y's service (incentive and/or precondition),
- q is supported

Phase-1: Generation (Formal)

Goal Support

Given a conjunction of propositions $d' = r_1 \wedge \ldots \wedge r_n$, an agent $x = \langle \mathcal{G}, \mathcal{A}, \mathcal{B} \rangle$ and a set of commitments $\mathcal{C}$, x *supports* d' with respect to commitments $\mathcal{C}$, denoted as $x, \mathcal{C} \Vdash r_1 \wedge \ldots \wedge r_n$, with respect to the following conditions.

- $x, \mathcal{C} \Vdash d'$ iff $d' = \top$
- $x, \mathcal{C} \Vdash d'$ iff $d' = d_i \wedge d_j$ and $x, \mathcal{C} \Vdash d_i$ and $x, \mathcal{C} \Vdash d_j$
- $x, \mathcal{C} \Vdash r$ iff $A_x(d, r') \in \mathcal{A}$ and $r' \Rightarrow r$ and $x, \mathcal{C} \Vdash d$

  or

  $C(y, x, d \wedge w, r) \in \mathcal{C}$ and $S_x(y, d, r') \in \mathcal{B}$ and $r' \Rightarrow r$ and $I_x(y, w, r) \in \mathcal{B}$ and $x, \mathcal{C} \Vdash d \wedge w$

Running example (1)

- Five agents: Customer, Builder 1, Builder 2, Merchant, Retail store
- The customer wants to have a certain type of furniture
- Builder 1 offers a service to build custom furniture if the materials for the furniture are supplied
- Builder 2 offers a service to assemble furniture if both materials and tools are provided
- Merchant sells ready-to-use furniture
- Retail store sells tools and materials
- Customer's domain knowledge tells that all these four providers would like to be paid for services.

Running example (2)

Table: Propositions of the running example and their meanings.

HaveFurniture	the customer owns furniture
HaveMaterials	the customer owns materials
HaveTools	the customer owns tools
MaterialsPaid	the customer has paid the retailer for the materials
ToolsPaid	the customer has paid the retailer for the tools
FurniturePaid	the customer has paid the merchant for the furniture
$Bui_1 Paid$	the customer has paid the service cost to the first builder
$Bui_2 Paid$	the customer has paid the service cost to the second builder
$Bui_1 MaterialsProvided$	the customer has provided materials to the first builder
$Bui_2 MaterialsProvided$	the customer has provided materials to the second builder
ToolsProvided	the customer has provided the tools to the second builder

Running example (3)

The goal of the customer is $g_1 = G_{Cus}(\mathit{HaveFurniture})$ (i.e., $\mathcal{G} = \{g_1\}$).

Table: Abilities of the customer.

a_1	$A_{Cus}(\mathit{HaveTools}, \mathit{ToolsProvided})$
a_2	$A_{Cus}(\mathit{HaveMaterials}, \mathit{Bui_1 MaterialsProvided})$
a_3	$A_{Cus}(\mathit{HaveMaterials}, \mathit{Bui_2 MaterialsProvided})$
a_4	$A_{Cus}(\top, \mathit{MaterialsPaid})$
a_5	$A_{Cus}(\top, \mathit{ToolsPaid})$
a_6	$A_{Cus}(\top, \mathit{FurniturePaid})$
a_7	$A_{Cus}(\top, \mathit{Bui_1 Paid})$
a_8	$A_{Cus}(\top, \mathit{Bui_2 Paid})$

Running example (4)

Table: Beliefs of the customer.

s_1	$S_{Cus}(Ret, \top, HaveMaterials)$
s_2	$S_{Cus}(Ret, \top, HaveTools)$
s_3	$S_{Cus}(Mer, \top, HaveFurniture)$
s_4	$S_{Cus}(Bui_1, Bui_1 MaterialsProvided, HaveFurniture)$
s_5	$S_{Cus}(Bui_2, Bui_2 MaterialsProvided \wedge ToolsProvided, HaveFurniture)$
n_1*	$I_{Cus}(Ret, MaterialsPaid, HaveMaterials)$
n_2*	$I_{Cus}(Ret, MaterialsPaid, HaveTools)$
n_3	$I_{Cus}(Ret, ToolsPaid, HaveTools)$
n_4	$I_{Cus}(Ret, ToolsPaid, HaveMaterials)$
n_5	$I_{Cus}(Mer, FurniturePaid, HaveFurniture)$
n_6	$I_{Cus}(Bui_1, Bui_1 Paid, HaveFurniture)$
n_7	$I_{Cus}(Bui_2, Bui_2 Paid, HaveFurniture)$

An example commitment protocol that supports the customer's goal (i.e., *HaveFurniture*):

$$c_1 = C(Ret, Cus, MaterialsPaid, HaveMaterials)$$
$$c_2 = C(Ret, Cus, ToolsPaid, HaveTools)$$
$$c_3 = C(Bui_2, Cus, Bui_2 MaterialsProvided \wedge ToolsProvided \wedge Bui_2 Paid, HaveFurniture)$$

Phase-1: Generation (Algorithm)

- Definition of support provides a recursive algorithm.
- Use a depth-first traversal to generate protocols
  - For each goal, either find an ability or a commitment do realize it.
  - If a precondition or a condition for the commitment is not satisfied, add it as a goal.
  - For cases, where a goal support is computed, reuse it.
  - The set of commitments generated forms a possible protocol.
- An efficient divide-and-conquer algorithm using dynamic programming is possible.

Generated protocols for the running example

p_1	$C(Mer, Cus, FurniturePaid, HaveFurniture)$
p_2	$C(Ret, Cus, MaterialsPaid, HaveMaterials)$ $C(Bui_1, Cus, Bui_1 MaterialsProvided \wedge Bui_1 Paid, HaveFurniture)$
p_3	$C(Ret, Cus, ToolsPaid, HaveMaterials)$ $C(Bui_1, Cus, Bui_1 MaterialsProvided \wedge Bui_1 Paid, HaveFurniture)$
p_4	$C(Ret, Cus, MaterialsPaid, HaveMaterials)$ $C(Ret, Cus, ToolsPaid, HaveTools)$ $C(Bui_2, Cus, Bui_2 MaterialsProvided \wedge ToolsProvided \wedge Bui_2 Paid, HaveFurniture)$
p_5	$C(Ret, Cus, ToolsPaid, HaveMaterials)$ $C(Ret, Cus, ToolsPaid, HaveTools)$ $C(Bui_2, Cus, Bui_2 MaterialsProvided \wedge ToolsProvided \wedge Bui_2 Paid, HaveFurniture)$
p_6	$C(Ret, Cus, MaterialsPaid, HaveMaterials)$ $C(Ret, Cus, MaterialsPaid, HaveTools)$ $C(Bui_2, Cus, Bui_2 MaterialsProvided \wedge ToolsProvided \wedge Bui_2 Paid, HaveFurniture)$
p_7	$C(Ret, Cus, ToolsPaid, HaveMaterials)$ $C(Ret, Cus, MaterialsPaid, HaveTools)$ $C(Bui_2, Cus, Bui_2 MaterialsProvided \wedge ToolsProvided \wedge Bui_2 Paid, HaveFurniture)$

Phase-2: Ranking

- Objective: to (subjectively) rank the candidate protocols
- Ranking is based on the protocols' utilities for *successful* executions
- Utility: benefit of protocol - cost of protocol
- Benefit: utility of goals + utility of side effects
- Cost: cost of capabilities the generator agent utilizes
- Things to consider:
  - Computing utilities for individual commitments
  - Best, worst and average case utilities of protocols

Cost of services and benefit of relevant propositions

- Assume $cost_x(A_x(d, r))$ and $benefit_x(r)$ is known
- Cost of a *proposition* is the maximal possible cost over the services that could be used to bring about the proposition

$$cost_x(r) = \max_{A_x(d',r') \in \mathcal{A} \wedge r' \Rightarrow r} cost_x(A_x(d', r'))$$

Ability	Cost
$a_1 = A_{Cus}(HaveTools, ToolsProvided)$	5
$a_2 = A_{Cus}(HaveMaterials, Bui_1 MaterialsProvided)$	1
$a_3 = A_{Cus}(HaveMaterials, Bui_2 MaterialsProvided)$	1
$a_4 = A_{Cus}(\top, MaterialsPaid)$	2
$a_5 = A_{Cus}(\top, ToolsPaid)$	3
$a_6 = A_{Cus}(\top, FurniturePaid)$	12
$a_7 = A_{Cus}(\top, Bui_1 Paid)$	4
$a_8 = A_{Cus}(\top, Bui_2 Paid)$	5

Proposition	Benefit
HaveFurniture	15
HaveTools	8
HaveMaterials	0

Utility of a protocol

Important to factor in evidence once (e.g., ToolsPaid is the precondition for two commitments, count the cost only once).

$$
\begin{aligned}
\mathit{utility}_x(p) &= \mathit{benefit}_x(p) - \mathit{cost}_x(p) \\
\mathit{benefit}_x(p) &= \sum_{r \in m \cup g} \mathit{benefit}_x(r) \\
&\quad \text{where } m = \bigcup_{c \in p} \mathit{rel}_x^{\mathit{benefit}}(c) \text{ and } g = \{r \mid G_x(r) \in \mathcal{G}\} \\
\mathit{cost}_x(p) &= \sum_{r \in m} \mathit{cost}_x(r) \\
&\quad \text{where } m = \bigcup_{c \in p} \mathit{rel}_x^{\mathit{cost}}(c)
\end{aligned}
\tag{1}
$$

- Cost of p_5: $\mathit{cost}_{Cus}(a_5) + \mathit{cost}_{Cus}(a_3) + \mathit{cost}_{Cus}(a_1) + \mathit{cost}_{Cus}(a_8) = 3 + 1 + 5 + 5 = 14$
- Benefit of p_5: Computed based on relevant propositions, *HaveMaterials*, *HaveTools* and *HaveFurniture*: $0 + 8 + 15 = 23$
- Utility of p_5: $23 - 14 = 9$

Customer's evaluation of protocol utility

	Benefit	Cost	Utility	Cost Rank	Utility Rank
p_1	15	12	3	3	7
p_2	15	7	8	1	3
p_3	15	8	7	2	5
p_4	23	16	7	6.5	5
p_5	23	14	9	5	2
p_6	23	13	10	4	1
p_7	23	16	7	6.5	5

Choose based on Benefit, Cost or Utility?

Phase-2: Ranking (Incorporating Risk)

- Can we use other information for better ranking?
- Utility: *risk discounted benefit* - cost
- Benefit is determined according to *trust* relations, where $T_x(y, S_x(y, d, r)) \in [0, 1]$.
  - Represents how likely y is to complete a service from x's perspective
  - Only applicable if x believes y can provide the service
  - For services that x will perform, its trust is trivially 1.
- Incorporation of risk provides a more fine-grained ranking.

Computing trust

- x considers all services that would enable r to be realized and combines the trust for these services using an auxiliary function $\oplus$.
- This auxiliary function can be defined using max, i.e. $T_x(y, s_1) \oplus T_x(y, s_2) = \max(T_x(y, s_1), T_x(y, s_2))$, meaning that the combined trust can at most be equal to the most trusted service.
- Necessary to consider the precondition: $T_x^p(y, r)$

$$T_x^p(y, r) = \begin{cases} 0, & \text{if } \neg\exists\ S_x(y, d, r') \in \mathcal{B} \text{ such that } r' \Rightarrow r \\ \bigoplus_{S_x(y,d,r') \in \mathcal{B} \wedge r' \Rightarrow r} T_x(y, S_x(y, d, r')) \times T_x^p(d), & \text{otherwise} \end{cases} \quad (2)$$

$$T_x^p(q_1 \wedge q_2) = T_x^p(q_1) \times T_x^p(q_2) \quad (3)$$

$$T_x^p(r) = T_x^p(x, r) \oplus \bigoplus_{C(y,x,d \wedge w,r') \in p \ \wedge\ r' \Rightarrow r} T_x^p(y, r) \quad (4)$$

Discounted utility

- Update the benefit considering how likely it is to come from certain agents

$$benefit_x(p) = \sum_{r \in m \cup g} benefit_x(r) \times T_x^p(r)$$

$$\text{where } m = \bigcup_{c \in p} rel_x^{benefit}(c) \text{ and } g = \{r \mid G_x(r) \in \mathcal{G}\}$$

- Benefit for p_4 (relevant propositions $m = \{HaveMaterials, HaveTools, HaveFurniture\}$)

Service	Trust
$s_1 = S_{Cus}(Ret, \top, HaveMaterials)$	0.7
$s_2 = S_{Cus}(Ret, \top, HaveTools)$	0.6
$s_3 = S_{Cus}(Mer, \top, HaveFurniture)$	0.9
$s_4 = S_{Cus}(Bui_1, Bui_1 MaterialsProvided, HaveFurniture)$	0.8
$s_5 = S_{Cus}(Bui_2, Bui_2 MaterialsProvided \wedge ToolsProvided, HaveFurniture)$	0.2

Customer's trust of services (1)

$$
\begin{aligned}
\mathit{benefit}_{Cus}(p_4) &= (\mathit{benefit}_{Cus}(\mathit{HaveMaterials}) \times T^{p_4}_{Cus}(\mathit{HaveMaterials})) \\
&\quad +(\mathit{benefit}_{Cus}(\mathit{HaveTools}) \times T^{p_4}_{Cus}(\mathit{HaveTools})) \\
&\quad +(\mathit{benefit}_{Cus}(\mathit{HaveFurniture}) \times T^{p_4}_{Cus}(\mathit{HaveFurniture}) \\
&= 0 + (8 \times T^{p_4}_{Cus}(\mathit{HaveTools})) + (15 \times T^{p_4}_{Cus}(\mathit{HaveFurniture}))
\end{aligned}
$$

$$
\begin{aligned}
&T^{p_4}_{Cus}(\mathit{HaveTools}) \\
&\quad = T_{Cus}(\mathit{Ret}, S_{Cus}(\mathit{Ret}, \top, \mathit{HaveTools})) \times T^{p_4}_{Cus}(\top) = 0.6 \times 1 = 0.6 \\
&T^{p_4}_{Cus}(\mathit{HaveFurniture}) \\
&\quad = T_{Cus}(\mathit{Bui}_2, S_{Cus}(\mathit{Bui}_2, \mathit{Bui}_2\mathit{MaterialsProvided} \\
&\qquad\qquad \wedge \mathit{ToolsProvided}, \mathit{HaveFurniture})) \\
&\qquad \times T^{p_4}_{Cus}(\mathit{Bui}_2\mathit{MaterialsProvided} \wedge \mathit{ToolsProvided}) \\
&\quad = 0.2 \times T^{p_4}_{Cus}(\mathit{Bui}_2\mathit{MaterialsProvided}) \times T^{p_4}_{Cus}(\mathit{ToolsProvided})
\end{aligned}
$$

Customer's trust of services (2)

$$T^{p_4}_{Cus}(Bui_2MaterialsProvided)$$
$$= T^{p_4}_{Cus}(HaveMaterials) = T_{Cus}(Ret, s_1) \times T^{p_4}_{Cus}(\top) = 0.7 \times 1 = 0.7$$
$$T^{p_4}_{Cus}(ToolsProvided) = T^{p_4}_{Cus}(HaveTools) \ = \ 0.6$$

$$T^{p_4}_{Cus}(HaveFurniture)$$
$$= 0.2 \times T^{p_4}_{Cus}(Bui_2MaterialsProvided) \otimes T^{p_4}_{Cus}(ToolsProvided)$$
$$= 0.2 \times 0.7 \times 0.6 \ = \ 0.084$$
$$benefit_{Cus}(p_4)$$
$$= 0 + (8 \times T^{p_4}_{Cus}(HaveTools)) + (15 \times T^{p_4}_{Cus}(HaveFurniture))$$
$$= 0 + (8 \times 0.6) + (15 \times 0.084) \ = \ 6.06$$

Customer's evaluation of protocol's expected value for utility

	Risk-Discounted Benefit	Cost	Expected Value for Utility	Expected Rank
p_1	13.5	12	1.5	1
p_2	8.4	7	1.4	2
p_3	8.4	8	0.4	3
p_4	6.06	16	-9.94	6.5
p_5	6.06	14	-7.94	5
p_6	6.06	13	-6.94	4
p_7	6.06	16	-9.94	6.5

Phase 3 and Phase 4: Agreement & enactment

- Agents should agree on a candidate protocol before enactment.
- Generator agent offers candidate protocols to others using ranking results until all agents agree to participate on a protocol.
- Ranking results can be used in different ways to guide the agreement procedure, e.g. strategies.
- Once agreed on the protocol, various operations (e.g., accept, ponens, etc.) can be applied

Summary & Future Work

- Summary:
  - Development of an agent framework for generation and enactment of commitment protocols at run-time.
  - Definition of goal support and corresponding algorithms for protocol generation.
  - Utility-based evaluation and ranking of protocols.
  - An agreement procedure to select a protocol using monotonic concession.
- Future Work:
  - Investigation of different evaluation criteria (robustness!).
  - Properties of agreement procedure.
  - Distributed protocol creation.