Projecting temporal properties, events & actions

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Gothenburg, 25 May 2019 (IWCS)

- Labels in records and record-types
- Statives (Dowty aspect hypothesis)
- Non-statives & Aktionsart (Moens & Steedman) $\rightsquigarrow$ episodes)
  Epilog (Schubert)
- Finite-state methods
  – MSO under projections
  Allen interval networks and beyond

Finitization & computability

Timeline $\mathbb{R}$ (DRT, Kamp & Reyle)
unbounded linear order (Allen & Ferguson)

$$X = \bigcup Fin(X) \text{ where } Fin(X) := \{A \subseteq X \mid A \text{ is finite}\}$$

$$(X, <) \;\cong\; \lim_{\leftarrow} \{<_A\}_{A \in Fin(X)} \qquad \text{projections}$$

$$<_{\{a_1,\ldots,a_n\}} \quad \text{as string} \quad a_1 \cdots a_n \quad \text{where } a_1 < \cdots < a_n$$

Trakhtenbrot's theorem *It is undecidable whether a first-order sentence with a binary relation has a finite model.*

Büchi-Elgot-Trakhtenbrot theorem (MSO = Reg)
For any finite set A and set L of strings over A,
an MSO_A-sentence defines L iff a finite automaton accepts L.

Aktionsart in strings

VENDLER, *Moens & Steedman* (Comrie)

	atomic	*extended*
	ACHIEVEMENT	ACCOMPLISHMENT
$+$*conseq*	*culmination*	*culminated process*
STATE a	$\boxed{\bar{a}}\boxed{a}$	$\boxed{\bar{a},\mathrm{ap}(f)}\boxed{\bar{a},\mathrm{ap}(f),\mathrm{ef}(f)}\boxed{\mathrm{ef}(f),a}$
	(semelfactive)	ACTIVITY
$-$*conseq*	*point*	*process*
f	$\boxed{\mathrm{ap}(f)}\boxed{\mathrm{ef}(f)}$	$\boxed{\mathrm{ap}(f)}\boxed{\mathrm{ap}(f),\mathrm{ef}(f)}\boxed{\mathrm{ef}(f)}$

force f	state a	
`hit`	`break`	Fillmore
manner	result	Levin & Rappaport Hovav

Variations on a theme of S^{c}h$_{u}$b$_{e}$r^{t}

	Davidson (event)	Barwise & Perry (situation)
Episodic Logic	characterize **	true-in *
Here	project wrt $\ell \subseteq A$	$\models_A$ (MSO)
	$\{\langle \ell_i, s_i \rangle\}_{i \in I}$	$\langle A, L \rangle$

Vary finite set A (ℓ) of

- temporal properties, stative and non-stative

- variables as in Constraint Satisfaction Problem *Var, Dom, Con*
  $\approx$ *institution* (Goguen & Burstall) *Sign, Mod, sen*

- random variables, or vertices in graphical model (cond independ)
  subset $\ell_i \approx$ clique in Markov network

> . . . *causally or otherwise contingently related sequences of events, which we might call* **episodes**
>
> – Moens & Steedman

Reducts & the border translation

ℓ-reduct $\rho_\ell(s)$ of s sees only symbols in ℓ

$$\rho_\ell(\alpha_1 \cdots \alpha_n) \;:=\; (\alpha_1 \cap \ell) \cdots (\alpha_n \cap \ell)$$

$$\rho_{\{a,a'\}}(\boxed{}\boxed{a}\boxed{a,a'}\boxed{a,a',a''}\boxed{a',a''}\boxed{a''}) \;=\; \boxed{}\boxed{a}\boxed{a,a'}\boxed{a,a'}\boxed{a'}\boxed{}$$

$$b(\boxed{}\boxed{a}\boxed{a,a'}\boxed{a,a'}\boxed{a'}) \;=\; \boxed{l(a)}\boxed{l(a')}\boxed{}\boxed{r(a)}\boxed{r(a')}$$

$b : (2^A)^* \to (2^{A_\bullet})^*,\ \alpha_1 \cdots \alpha_n \mapsto \beta_1 \cdots \beta_n$

$$A_\bullet \;:=\; \{l(a) \mid a \in A\} \cup \{r(a) \mid a \in A\}$$
$$\beta_n \;:=\; \{r(a) \mid a \in \alpha_n\}$$
$$\beta_i \;:=\; \{l(a) \mid a \in \alpha_{i+1} - \alpha_i\} \cup \{r(a) \mid a \in \alpha_i - \alpha_{i+1}\} \quad \text{for } i < n$$

$$P_{l(a)}(x) \;\equiv\; \neg P_a(x) \wedge (\exists y)(xSy \wedge P_a(y))$$

Compression two ways & projection

$\boxed{}\boxed{a}\boxed{a,a'}\boxed{a,a'}\boxed{a'} \overset{bc}{\to} \boxed{}\boxed{a}\boxed{a,a'}\boxed{a'}$ no stutters

$\downarrow b$ border translation

$\boxed{l(a)}\boxed{l(a')}\boxed{}\boxed{r(a)}\boxed{r(a')} \overset{d_\Box}{\to} \boxed{l(a)}\boxed{l(a')}\boxed{r(a)}\boxed{r(a')}$ no $\Box$

$$d_\Box(s) \;:=\; s \text{ without } \Box$$
$$d_\ell(s) \;:=\; d_\Box(\rho_\ell(s))$$

s projects to s' if $s' = d_{voc(s')}(s)$ where

$$voc(\alpha_1 \cdots \alpha_n) \;:=\; \bigcup_{i=1}^{n} \alpha_i .$$

a is an *s-interval* if $b(s)$ projects to $\boxed{l(a)}\boxed{r(a)}$

Leibniz's law: identity of indiscernibles relativized

$$x \neq y \;\supset\; (\exists P)\neg(P(x) \equiv P(y)) \qquad \text{(LL)}$$

replace $\neq$ by adjacency S "time steps$_S$ only with change$_A$"

$$xSy \;\supset\; x \not\equiv_A y \qquad (\mathrm{LL}_A)$$

and take P from a finite set A

$$x \not\equiv_A y \;:=\; \bigvee_{a \in A} \neg(P_a(x) \equiv P_a(y)) \qquad \text{bc}$$

$$\equiv \bigvee_{a \in A} \underbrace{(\neg P_a(x) \wedge P_a(y))}_{P_{l(a)}(x)} \vee \underbrace{(P_a(x) \wedge \neg P_a(y))}_{P_{r(a)}(x)} \qquad \mathrm{d}_\square$$

Projecting more than once

$$\mathcal{L}_A \;:=\; \{\mathrm{d}_\square(s) \mid s \in (2^A)^+\} \qquad \text{Schwer } S\text{-words}$$

$$\mathcal{L}_A(s) \;:=\; \{s' \in \mathcal{L}_A \mid s' \text{ projects to } s\}$$

$$\mathcal{L}_A(\boxed{l(a)}\boxed{r(a)}) \cap \mathcal{L}_A(\boxed{l(a')}\boxed{r(a')}) = \overbrace{\mathrm{Allen}(a, a')}^{13 \text{ strings}} \quad \text{for } A = \{a, a'\}.$$

Define superposition $s\&s'$ such that

$$\mathcal{L}_A(s) \cap \mathcal{L}_A(s') \;=\; \mathcal{L}_A(s\&s') \quad \text{where}$$

$$\mathcal{L}_A(L) \;:=\; \bigcup_{s \in L} \mathcal{L}_A(s)$$

Allen relations projected

$$s \models aRa' \iff b(s) \text{ projects to } \mathfrak{s}_R(a,a')$$

R	aRa'	$\mathfrak{s}_R(a,a')$	R^{-1}	$\mathfrak{s}_{R^{-1}}(a,a')$
$<$	a before a'	$\boxed{l(a)}\boxed{r(a)}\boxed{l(a')}\boxed{r(a')}$	$>$	$\boxed{l(a')}\boxed{r(a')}\boxed{l(a)}\boxed{r(a)}$
m	a meets a'	$\boxed{l(a)}\boxed{r(a),l(a')}\boxed{r(a')}$	mi	$\boxed{l(a')}\boxed{r(a'),l(a)}\boxed{r(a)}$
o	a overlaps a'	$\boxed{l(a)}\boxed{l(a')}\boxed{r(a)}\boxed{r(a')}$	oi	$\boxed{l(a')}\boxed{l(a)}\boxed{r(a')}\boxed{r(a)}$
s	a starts a'	$\boxed{l(a),l(a')}\boxed{r(a)}\boxed{r(a')}$	si	$\boxed{l(a),l(a')}\boxed{r(a')}\boxed{r(a)}$
d	a during a'	$\boxed{l(a')}\boxed{l(a)}\boxed{r(a)}\boxed{r(a')}$	di	$\boxed{l(a)}\boxed{l(a')}\boxed{r(a')}\boxed{r(a)}$
f	a finishes a'	$\boxed{l(a')}\boxed{l(a)}\boxed{r(a),r(a')}$	fi	$\boxed{l(a)}\boxed{l(a')}\boxed{r(a),r(a')}$
$=$	a equal a'	$\boxed{l(a),l(a')}\boxed{r(a),r(a')}$	$=$	

Allen(a,a')

From 2 intervals to 3

$$\frac{a < a' \qquad a' < a''}{a < a''} \qquad\qquad \frac{a \text{ o } a' \qquad a' \text{ d } a''}{a \ \{\text{d,o,s}\}\ a''}$$

	$<$	o	d	$\cdots$
$<$	$<$	$<$	$<$ d m o s	$\cdots$
o	$<$	$<$ m o	d o s	$\cdots$
d	$<$	$<$ d m o s	d	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\cdots$

$$\mathfrak{s}_<(a,a')\ \&\ \mathfrak{s}_<(a',a'') = \boxed{l(a)}\boxed{r(a)}\boxed{l(a')}\boxed{r(a')}\boxed{l(a'')}\boxed{r(a'')}$$

$$\mathfrak{s}_{\text{o}}(a,a')\ \&\ \mathfrak{s}_{\text{d}}(a',a'') = \boxed{l(a'')}\boxed{l(a)}\boxed{l(a')}\boxed{r(a)}\boxed{r(a')}\boxed{r(a'')} \qquad a \text{ d } a''$$

$$+ \boxed{l(a)}\boxed{l(a'')}\boxed{l(a')}\boxed{r(a)}\boxed{r(a')}\boxed{r(a'')} \qquad a \text{ o } a''$$

$$+ \boxed{l(a),l(a'')}\boxed{l(a')}\boxed{r(a)}\boxed{r(a')}\boxed{r(a'')} \qquad a \text{ s } a''$$

Superposition

$$\frac{}{\&^\circ(\epsilon,\epsilon,\epsilon)} \qquad \frac{\&^\circ(s,s',s'')}{\&^\circ(\alpha s,\alpha' s,(\alpha\cup\alpha')s'')} \qquad \frac{\&^\circ(s,s',s'')}{\&^\circ(\alpha s,s',\alpha s'')} \qquad \frac{\&^\circ(s,s',s'')}{\&^\circ(s,\alpha' s',\alpha' s'')}$$

Constrain through A, A'

$$\frac{\&_{A,A'}(s,s',s'') \qquad \alpha\cap A'\subseteq\alpha' \qquad \alpha'\cap A\subseteq\alpha}{\&_{A,A'}(\alpha s,\alpha' s,(\alpha\cup\alpha')s'')}$$

$$\frac{\&_{A,A'}(s,s',s'') \qquad \alpha\cap A'=\emptyset}{\&_{A,A'}(\alpha s,s',\alpha s'')} \qquad \frac{\&_{A,A'}(s,s',s'') \qquad \alpha'\cap A=\emptyset}{\&_{A,A'}(s,\alpha' s',\alpha' s'')}$$

$\&_{voc(s),voc(s')}(s,s',s'') \iff \&^\circ(s,s',s'')$ and s'' projects to s and s'

Episodes in Moens & Steedman as record types

> Rather than a homogeneous database of dated points or intervals, we should partition it into distinct sequences of causally or otherwise contingently related sequences of events, which we might call **episodes** [MS, p 26]

$$\begin{aligned} [\![\{\langle \ell_i, L_i\rangle\}_{i\in I}]\!]_A &:= \{s\in\mathcal{L}_A \mid (\forall i\in I)\ d_{\ell_i}(s)\in L_i\} \\ &= \bigcap_{i\in I}\mathcal{L}_A(L_i) \quad \text{if } \ell_i = voc(s_i) \text{ for } i\in I \end{aligned}$$

E.g. interval network arc labeling $\lambda : (Ivl\times Ivl)\to 2^{AR}$

for $\ell_i=\{a,a'\},\ L_i=\{\mathfrak{s}_R(a,a')\mid R\in\lambda(a,a')\}$

determinate labeling $L_i=\{s_i\}$ for record

$$[\![\{\langle \ell_i, s_i\rangle\}_{i\in I}]\!]_A := \{s\in\mathcal{L}_A \mid (\forall i\in I)\ d_{\ell_i}(s) = s_i\}$$

J.A. Wheeler: *it from bit*

every *it* – every particle, every field of force, even the space-time continuum itself – derives its function, its meaning, its very existence entirely – even if in some contexts indirectly – from the apparatus-elicited answers to yes-or-no questions, binary choices, bits.

. . .

all things physical are information-theoretic in origin

it $\approx$ value/string v_i (or type/language T_i)
linked by ℓ_i in records (or record types)

MSO: yes-or-no P_a-questions answered in S-steps

T h a n k   Y o u

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