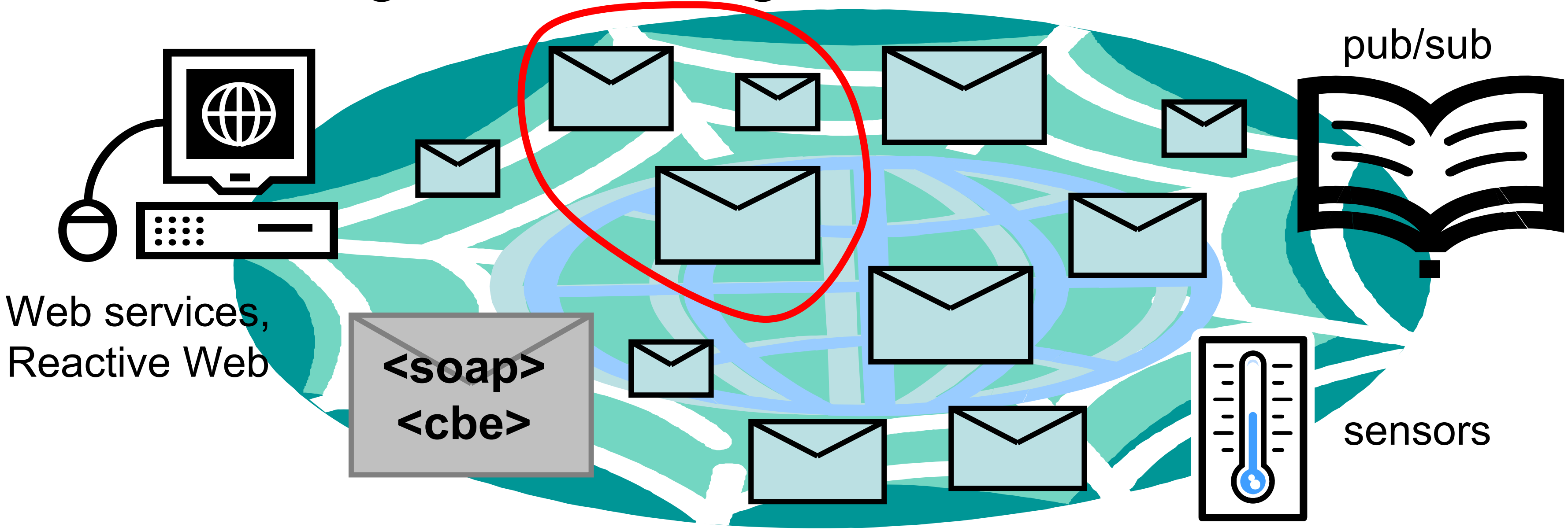
Rule-Based Composite Event Queries: The Language XChange^{EQ} and its Semantics

François Bry, Michael Eckert
LMU München

Motivation: Composite Events

Generating and reacting to events on the Web

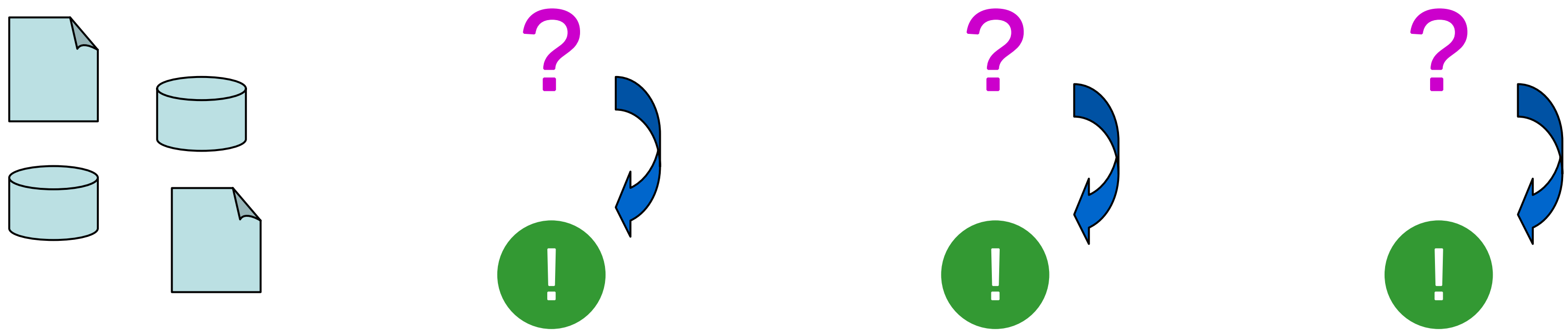


Composite Events

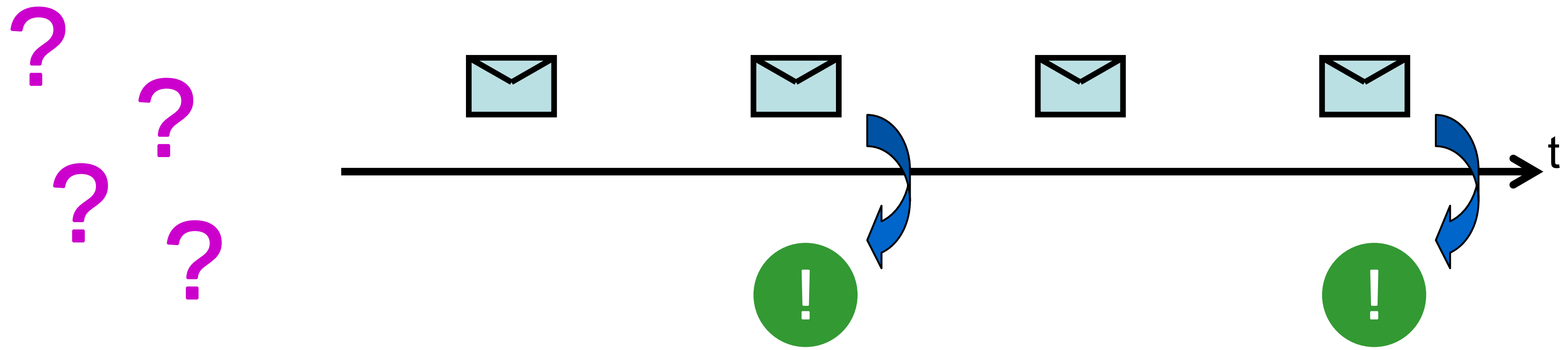
- Must be inferred from “atomic events” (messages)
- Multiple atomic events, relationship between them
- Need query language!

Queries against Event Streams

Database Queries, Web Queries:

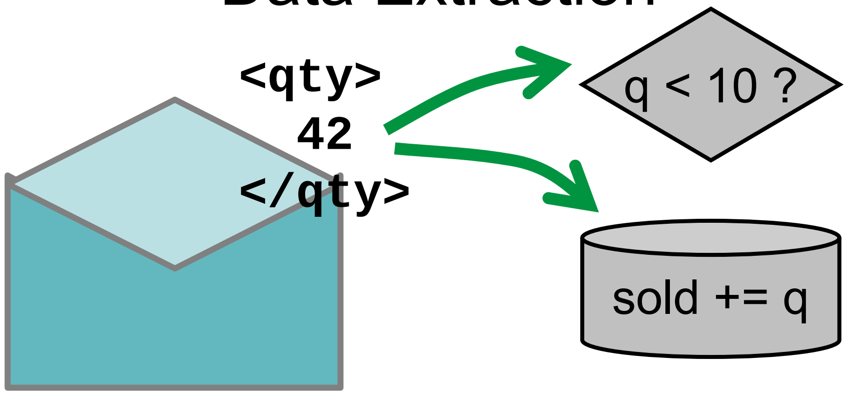


(Composite) Event Queries:

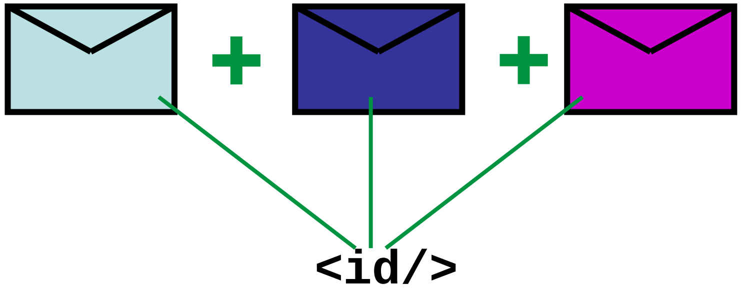


Language Requirements

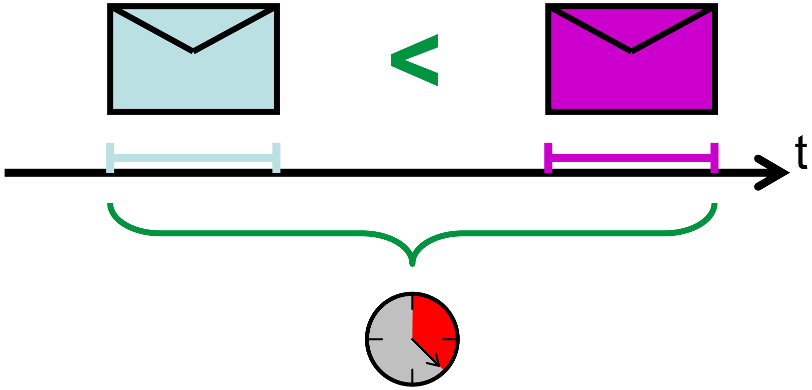
Data Extraction



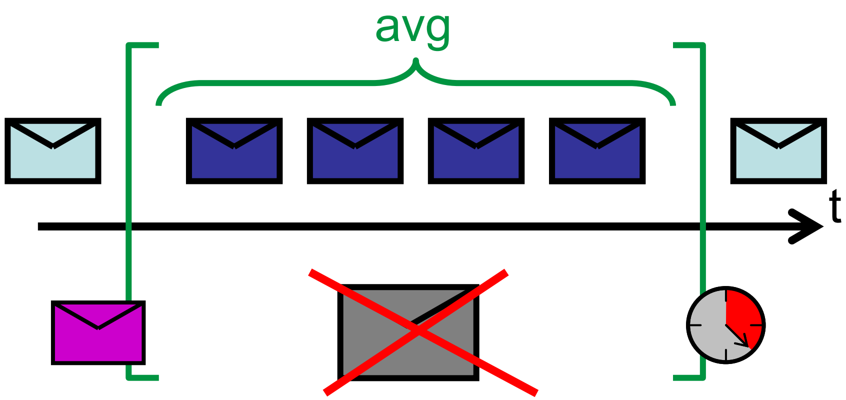
Event Composition



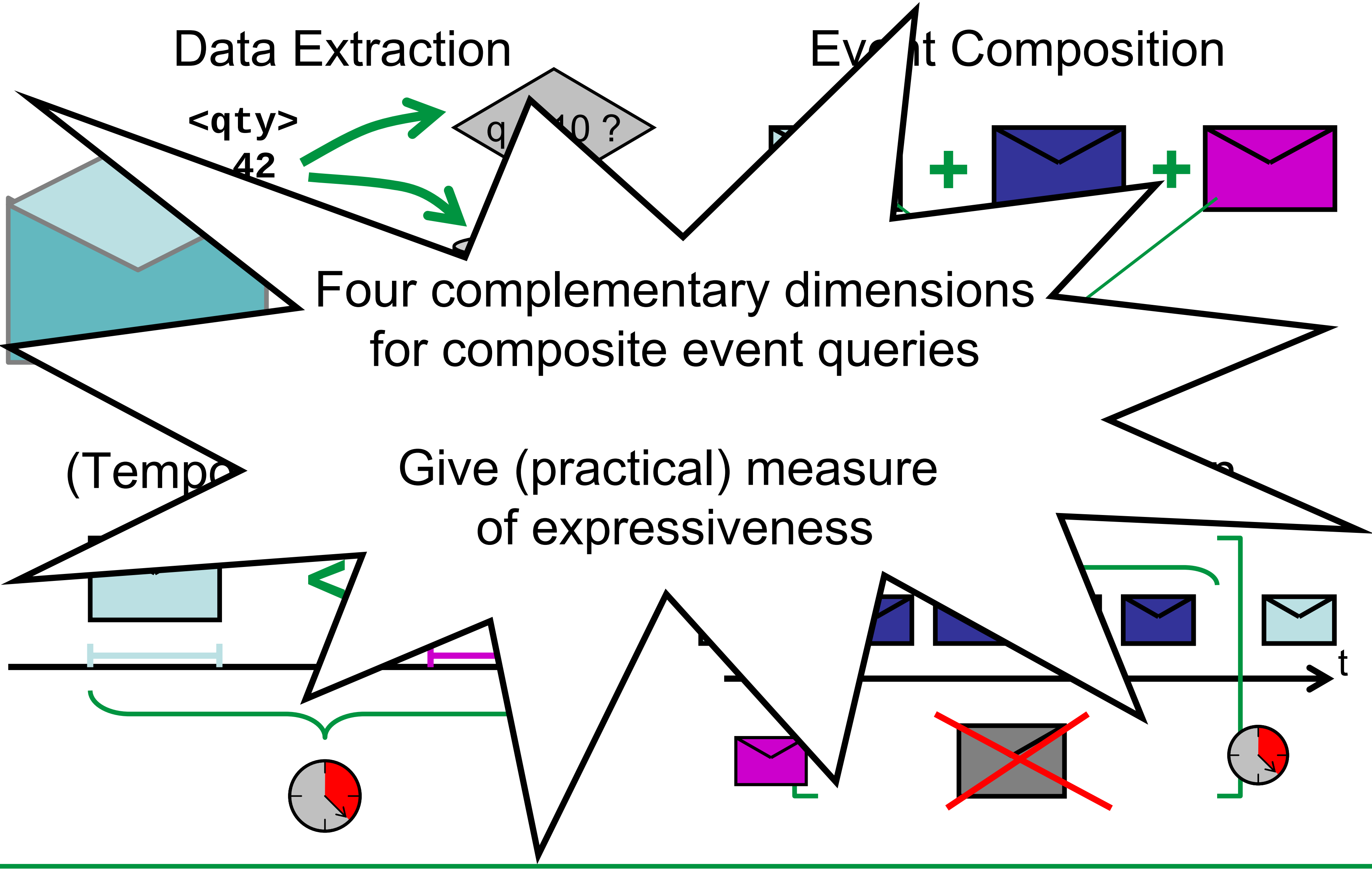
(Temporal) Relationships



Event Accumulation



Language Requirements



Four complementary dimensions
for composite event queries

Give (practical) measure
of expressiveness

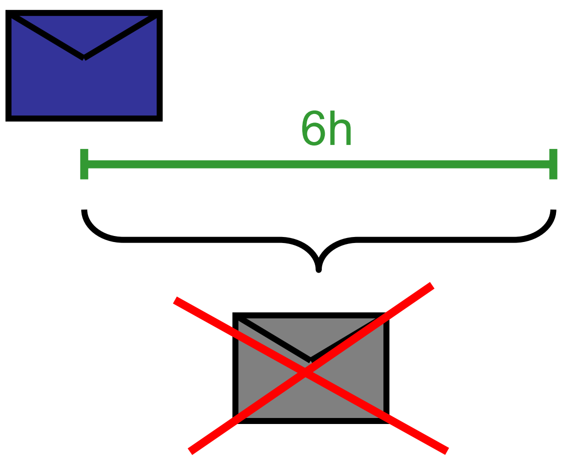
XChange^{EQ}: Rule-Based CEQs

- High-level, declarative query language for composite events, fully covers four dimensions
- Pattern-based queries on XML event messages: embeds Web query language Xcerpt
- Integrates into reactive rule language XChange
  - Perform automatic reactions, timing important
- Deductive (event) rules:
  - Define new, “virtual” events from received events
  - mediation, abstraction, reasoning (cf. database views)
  - Side-effect free; don’t implement by reactive rules: optimization, (human) understanding

XChange^{EQ}: Example Rule

```
DETECT
  overdue {
    id { var ID }
    cust { var C } }
ON
  and {
    event o: order {{
      id { var ID },
      quantity { var Q },
      cust { var C } }}
    event w: extend[o, 6h],
    while w: not shipped {{
      id { var ID } }}
  } where { var Q < 10 }
END
```

```
DETECT
  order {
    id { var ID},
    quantity { var C },
    cust { var C } }
FROM
  ...
END
```



Semantics (1)

- Declarative Semantics for XChangeEQ:
  model + fixpoint theories for stratified programs
  (A standard approach for rule languages)

- (Tarski-style) model theory:
  Define M $\models F^t$ recursively

$I, \Sigma, \tau \models (\texttt{event}\ i : q)^t$	iff exists $e^{t'} \in I$ with $\tau(i) = e^{t'}$, $t' = t$, and for all $e' \in \Sigma(q)$ we have $e' \preceq e$
$I, \Sigma, \tau \models (\texttt{event}\ i : \texttt{extends}[j, d])^t$	iff exists $e^{t'}$ with $\tau(j) = e^{t'}$, $\tau(i) = e^t$, $t = t' + d$
...	(Definitions for other temporal events are similar and skipped.)
$M \models (q_1 \wedge q_2)^t$	iff $M \models q_1^{t_1}$ and $M \models q_2^{t_2}$ and $t = t_1 \sqcup t_2$
$M \models (q_1 \vee q_2)^t$	iff $M \models q_1^t$ or $M \models q_2^t$
$I, \Sigma, \tau \models (Q\ \texttt{where}\ C)^t$	iff $I, \Sigma, \tau \models Q^t$ and $W_{\Sigma,\tau}(C) = true$
$I, \Sigma, \tau \models (\texttt{while}\ j :\ \texttt{not}\ q)^t$	iff exists $e^{t'}$ with $\tau(j) = e^{t'}$, $t' = t$, and for all $t'' \sqsubseteq t$ we have $I, \Sigma, \tau \not\models q^{t''}$
$I, \Sigma, \tau \models (\texttt{while}\ j :\ \texttt{collect}\ q)^t$	iff exists $e^{t'}$ with $\tau(j) = e^{t'}$, $t' = t$, and exist $n \geq 0$, $\Sigma_1, \ldots \Sigma_n$, $t_1 \sqsubseteq t, \ldots t_n \sqsubseteq t$ with $\Sigma = \bigcup_{i=1..n} \Sigma_i$, and for all $i = 1..n$ we have $I, \Sigma_i, \tau \models q^{t_i}$
$I, \Sigma, \tau \models (c \leftarrow Q)^t$	iff (1) $\Sigma'(c)^t \subseteq I$ for Σ' maximal (w.r.t. $FreeVars(Q)$) and τ' such that $I, \Sigma', \tau' \models Q^t$, or (2) $I, \Sigma', \tau' \not\models Q^t$ for all Σ', τ'

$W_{\Sigma,\tau}(i\ \texttt{before}\ j) = \mathbf{true}$	iff $end(\tau(i)) < begin(\tau(j))$
$W_{\Sigma,\tau}(i\ \texttt{during}\ j) = \mathbf{true}$	iff $begin(\tau(j)) < begin(\tau(i))$ and $end(\tau(i)) < end(\tau(j))$
$W_{\Sigma,\tau}(i\ \texttt{overlaps}\ j) = \mathbf{true}$	iff $begin(\tau(j)) < begin(\tau(i)) < end(\tau(j)) < end(\tau(i))$

- Accommodates event identifiers (“event o:”)
- Events have occurrence times
- Temporal relations: fixed interpretation

Semantics (2)

- Restriction to stratified programs
  - w.r.t. negation, grouping, *relative temporal events*
- Fixpoint: model $M_{P,E}$
  - $T_P(I)$: all events derivable by rules in P
  - starting with incoming event stream E
  - compute fixpoints stratum by stratum

$$P = P_1 \uplus \cdots \uplus P_n$$

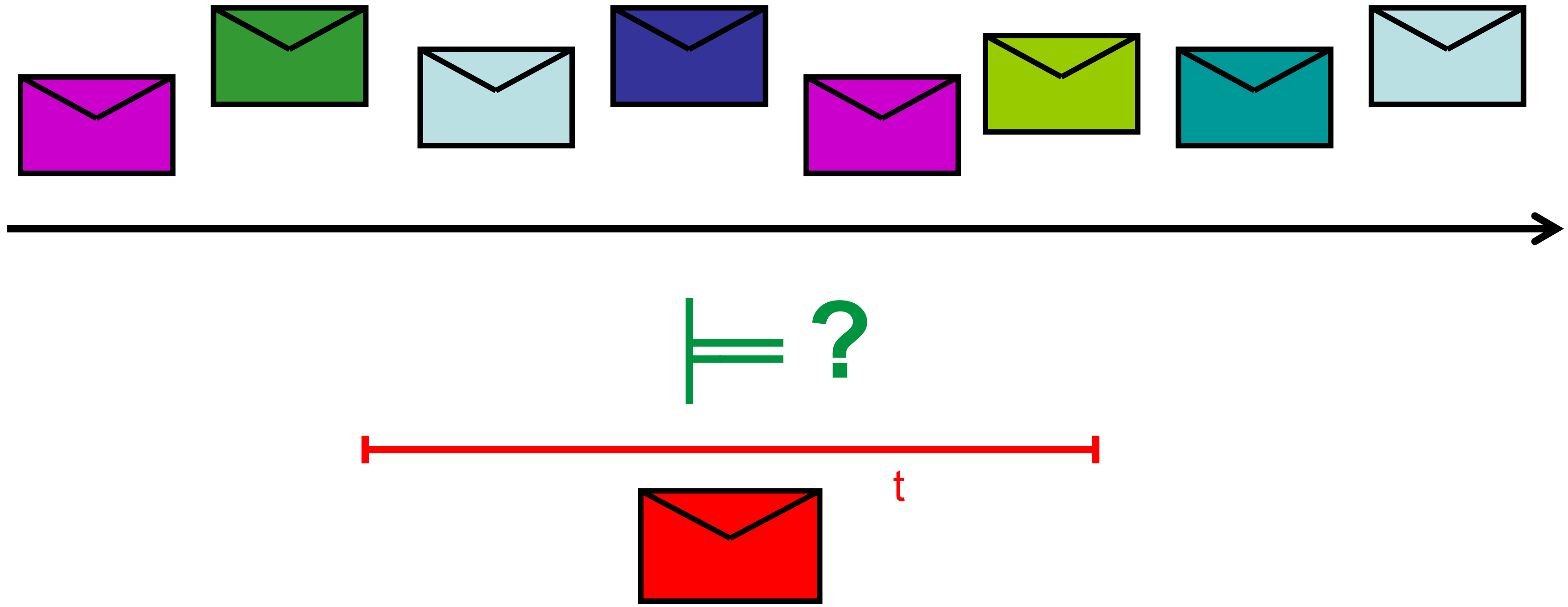
$$\begin{aligned} T_P(I) = I \cup \{e^t \mid {} & \text{there exist a rule } c \leftarrow Q \in P, \\ & \text{a maximal substitution set } \Sigma, \\ & \text{and a substitution } \tau \text{ s.t.} \\ & I, \Sigma, \tau \models Q^t \text{ and } e \in \Sigma(c)\} \end{aligned}$$

T_P^ω: least fixpoint of T_P

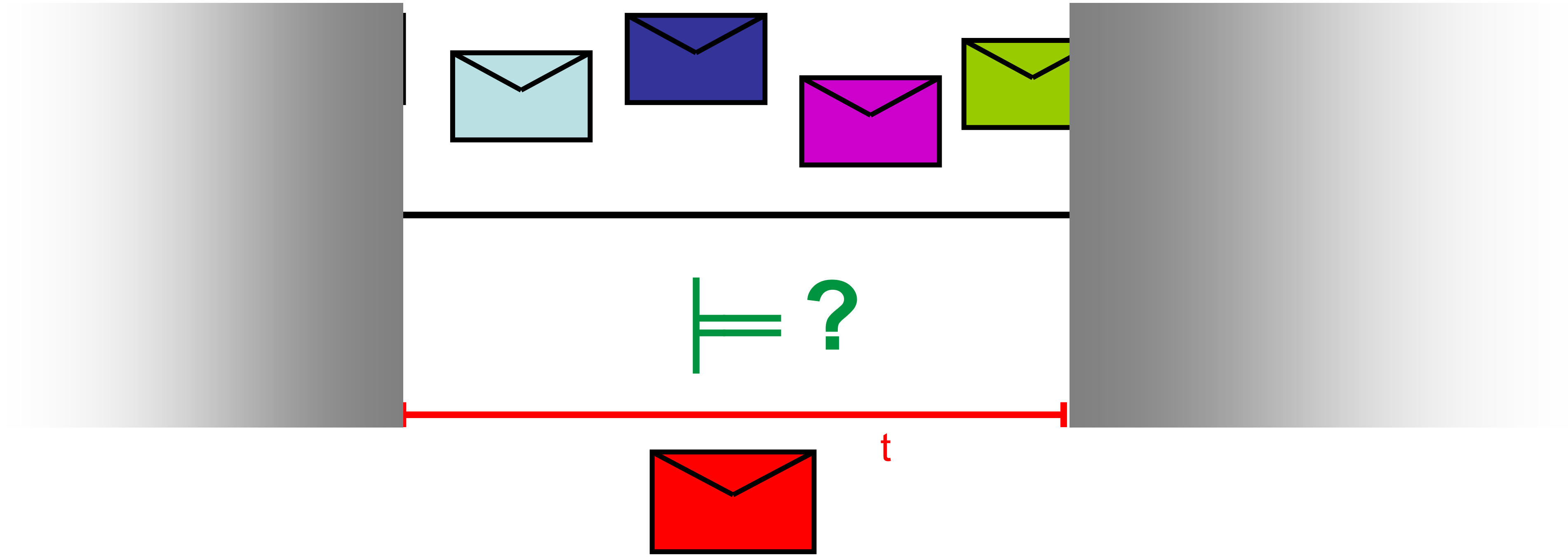
$$\begin{aligned} M_0 &= E = T_\emptyset^\omega(E), \\ M_1 &= T_{P_1}^\omega(M_0), \\ & \ldots, \\ M_n &= T_{P_n}^\omega(M_{n-1}) =: M_{P,E}. \end{aligned}$$

- Theorem:
  - P stratified program, E (incoming) event stream.
  - Then: $M_{P,E}$ is a minimal model of P under E and
  - Independent of the stratification of P

Unbounded Event Streams



Unbounded Event Streams



- XChange^{EQ}-Semantics are well-defined for *unbounded* ("infinite") incoming event streams E

$$M_{P,E} \mid t = M_{P,E|t} \mid t$$

Summary and Outlook

- XChange^{EQ}:
  - High-level event query language
  - Full coverage of all four dimensions, XML support
  - Support for (deductive) event rules
- Declarative Semantics
  - Model and fixpoint theory for stratified programs
  - Well-defined on unbounded event streams
- Outlook
  - Incremental, data-driven evaluation
  - Optimizations based on temporal conditions