

A Self-Organising Infrastructure for Chemical-Semantic Coordination

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Outline

Chemical Tuple Spaces

Chemical Tuple Spaces in TuCSoN

Bibliography

Chemical Tuple Spaces

Chemical tuple spaces for modelling interaction rules in ecosystems.

Main idea

- Tuple spaces + chemical-like reactions as coordination laws
- Tuples have a concentration (a.k.a. weight, or activity value)
- Concentration is evolved “exactly” as in chemistry [4]
- Some reactions can even fire a tuple from one space to another

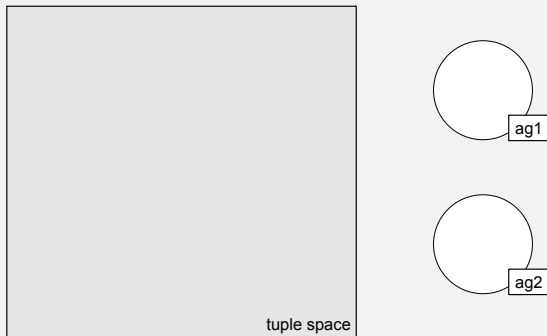
Why designing coordination with this chemical metaphor?

- Chemistry fits coordination (Gamma)
- Can get inspiration from natural/artificial (bio)chemistry
- Can model population dynamics (prey-predator [2])



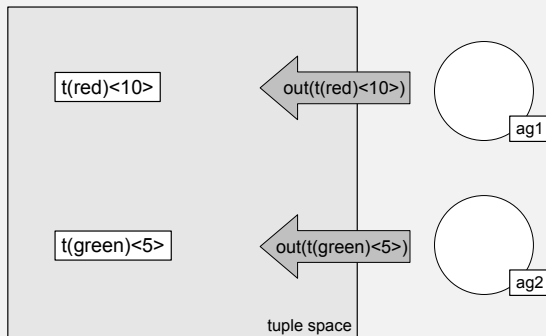
First settings

One tuple space, two agents



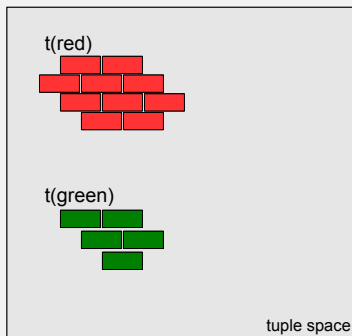
Inserting tuples

Primitive out: default concentration is 1



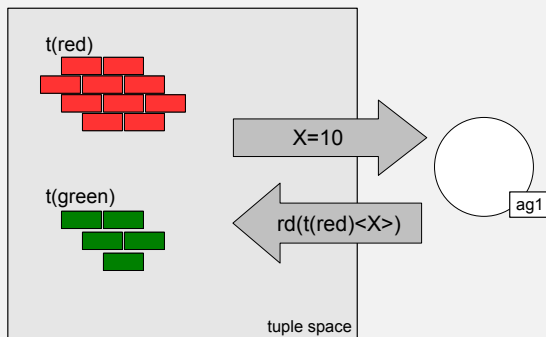
A pictorial representation

A tuple as substance of uniform molecules – still a single tuple



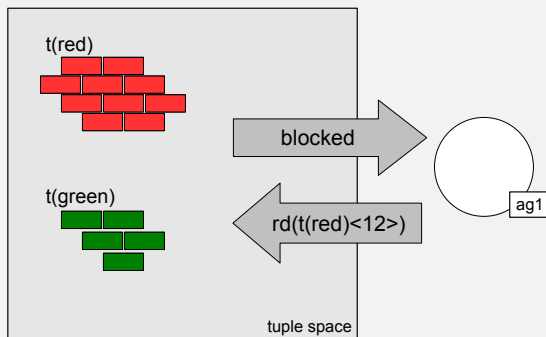
Reading Tuples

Primitive rd: reading current concentration



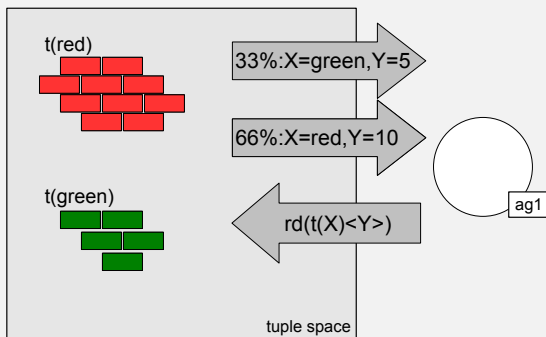
Reading Tuples

Primitive rd: reading a given amount – possibly blocking



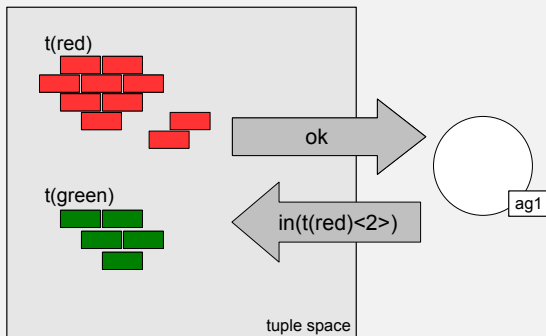
Reading Tuples

Primitive rd: concentration as probability, i.e., relevance



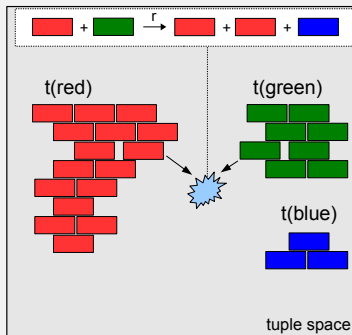
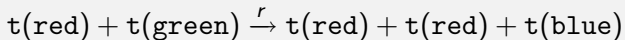
Removing Tuples

Primitive `in`: removing entirely or partially a tuple



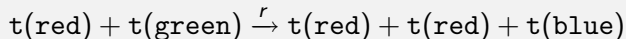
Installing Chemical Reactions

A chemical reaction, with tuples in place of molecules

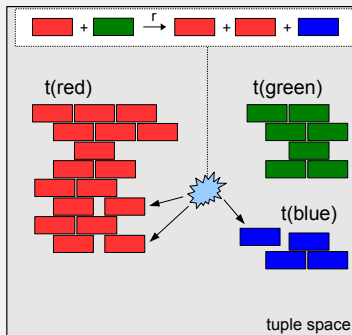


Firing Chemical Reactions

Reactions are executed over time according to [4]



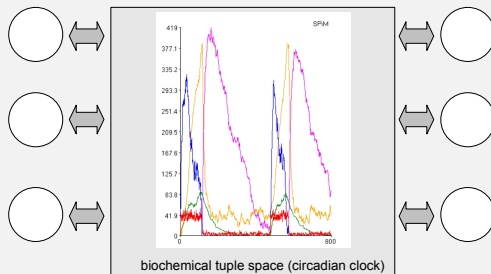
Transition (Markovian) rate: $r * \#t(\text{red}) * \#t(\text{green})$



A tuple space as a chemical solution

Coordination through an exact chemical solution of tuples

- The tuple space resembles a chemical solution in a glass
- Each tuple resembles a chemical substance
- Agents observe, insert and remove substances
- Tuple concentration drives the selection of chemical reactions



On matching and rates

Chemical reactions

- are general and not specific for particular chemical substances
 - as tuples, they are expressed in terms of templates
Example: $s(X) \xrightarrow{r} 0$ and $s(X) + r(Y) \xrightarrow{r} s(X) + s(X)$
 - the global rate depends from both r and the rates of matching substances becomes
Example: $s(sa) \xrightarrow{r} 0$ and $s(sa) + r(ra) \xrightarrow{r} s(sa) + s(sa)$
the rates are respectively $r \times \#sa$ and $r \times \#sa \times \#ra$



On matching and rates

Overcoming syntactic and discrete matching

- We use semantic matching in order to deal with openness requirements [8, 7]
 - We use an application-dependent fuzzy match function $\mu(t, t')$ in order to deal with vagueness of information [6]
 - $\mu = 0$ no match, $\mu = 1$ perfect match, $0 < \mu < 1$ partial
- the global rate has to be multiplied with μ



Some implementation facts

How and when selecting a chemical reaction?

Gillespie “direct” simulation algorithm for chemistry [4]

1. Compute the markovian rate $r_1, \dots, r_n$ of reactions, let R be the sum
2. Choose one of them probabilistically, and execute its transition
3. Proceed again with (1) after $\frac{1}{R} * \ln \frac{1}{\tau}$ seconds, with $\tau = \text{random}(0, 1)$

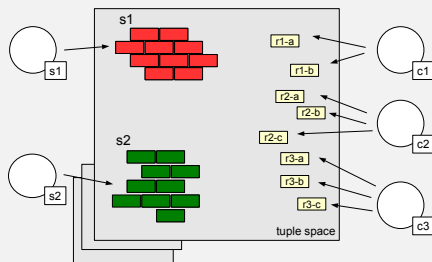
Tuple Space implementation

- Can be prototyped on top of TuCSoN
- Tuple centres programmed with the above algorithm
- Also need to implement proper matching



The scenario of service ecosystems

Services and requests as tuples



Clients and services as “individuals of an ecology”

- Unused services fade until completely disappearing
- Concentration of a service increases upon usage
- Similar services compete for survival

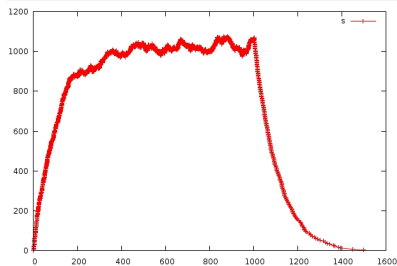


Positive-Negative feedback

Service tuples decay, but can be sustained by a feedback token

- Decay rule: $SER \xrightarrow{r_{dec}} 0$
- Feed rule: $publish(SER) \xrightarrow{r_{feed}} publish(SER) + SER$

Example simulation: $r_{dec} = 0.01, r_{feed} = 10$



- time 0: Catalyst Token $publish(S)$ is inserted
- time 400: Service S reaches an equilibrium
- time 1000: The token is removed (or decays)
- time 1600: Service S vanishes

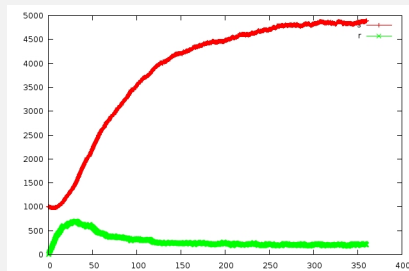


Feedback by using (a.k.a. prey-predator)

Idea: Matching Service-Request sustains the service

- Use rule: $SER + REQ \xrightarrow{r_use} SER + SER + toserve(SER, REQ)$

Sim: $r_dec = 0.01$, $r_use = 0.00005$, $request_arrival_rate = 50$



- time 0: Injection of requests raises service level
- time 30: Requests are tamed
- time 350: Unserved requests and service stabilise

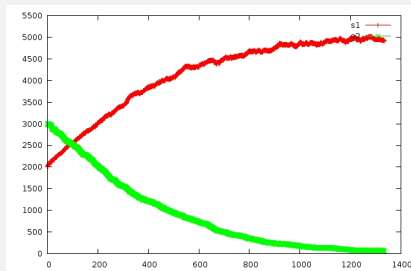


Competition

What if more services can handle the same requests?

- higher concentration means higher match frequency
- some service may match better the request, being more proper

Sim: $r_use_1 = 0.06, r_use_2 = 0.04$



- time 0: The two services are in competition for the same requests
- time 100: The one with better use rate (better match) is prevailing
- time 1300: Service s2 lost competition and fades



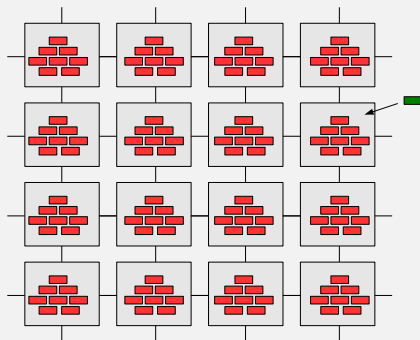
Spatial Diffusion and Competition

One service monopolises a network and its requests

Services continuously diffuse around, by rule:

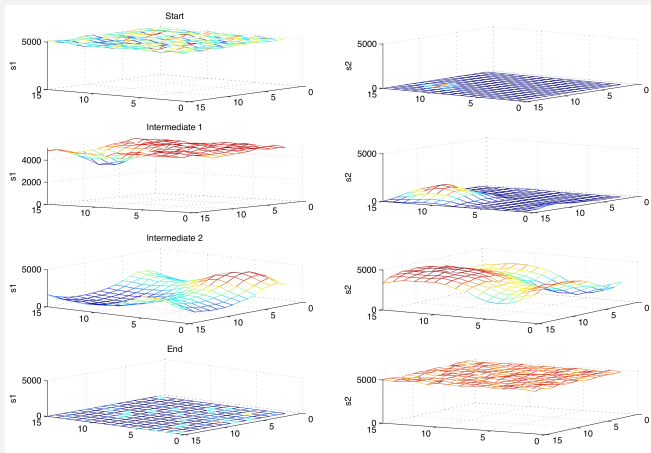
- Diffuse rule: $\text{SER} \xrightarrow{r_diff} \text{SER} \rightsquigarrow$

Scenario: a better service is injected in a node



Resembling a biological tissue scenario

Example Simulation: $r_{use_1} = 0.05, r_{use_2} = 0.1$



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- Modelling of reactants and laws through tuples
- Realisation of a chemical engine (Gillespie) through ReSpecT reactions
- Realisation of a no syntactic and a no discrete matching through semantic and fuzziness

Chemical reactants and laws

Reactants and laws

- Tuples as reactant individuals in the form `reactant(X,N)`
 - `reactant(sa,1000)` and `reactant(ra,1000)`
- Laws modelling chemical reactions as tuples in the form `law(InputList,Rate,OutputList)`
 - $S + R \xrightarrow{10.0} S + S$ becomes `law([S,R],10,[S,S])`

Matching and rates

- The law `law([S,R],10,[S,S])` is instantiated with reactants `ra` and `sa` obtaining `law([sa,ra],r1a,[sa,sa])`
- The rate `r1a` is calculated as $10.0 \times \#as \times \#ar \times \mu(S + R, sa + ra)$



Chemical reactions

Chemical engine as ReSpecT reactions

- Managing chemical laws and reactants
- Controlling engine start and stop
- Choosing the next chemical law to be executed (Gillespie's algorithm)
- Executing chemical laws

Semantic and fuzziness in TuCSoN

A new tuple space model [5]

- *Fuzzy domain ontology* allowing to interpret the semantics associated to the fuzzy knowledge (set of tuples) stored into a tuple space.
- *Fuzzy semantic tuples* fuzzy domain objects – represented by tuples – described so that they can be interpreted in a semantic way, by means of the domain ontology.
- *Fuzzy semantic templates* as fuzzy descriptions of a domain object set.
- *Fuzzy semantic matching* providing the fuzzy domain objects – tuples – described through fuzzy templates.



Semantic and fuzziness in TuCSoN

Fuzzy Description Logic as a formalism

- Fuzzy **SHOIN(D)** Description Logic formalism [1, 5, 6] to describe domain ontologies and objects.
 - Good compromise between expressiveness and complexity.
 - Theoretical counterpart of fuzzy **OWL DL**, that is one of the three species of W3C OWL. OWL being a standard, it well fits the openness requirement.

Semantic and fuzziness in TuCSoN

Tuple space ontology

- Fuzzy OWL DL [6]

Fuzzy semantic tuples

- A fuzzy SHOIN(D)-like language for tuples:

```
Individual ::= iname ':' C  
C ::= cname  $[\rightarrow \alpha]$  | cname '(' R  $[\rightarrow \alpha]$  ')'  
R ::= rname ':' V | rname 'in' '(' Vset ')' | R ',' R  
Vset ::= V  $[\rightarrow \alpha]$  | V  $[\rightarrow \alpha]$  ',' Vset  
V ::= iname | number | string
```

Example:

```
ca : 'CityCar' (hasMaker:ford, hasMaxSpeed:130,  
hasColour in (red $\rightarrow$  0.7, black $\rightarrow$  0.3))
```



Semantic and fuzziness in TuCSoN

Fuzzy semantic templates

- A fuzzy SHOIN(D)-like description language for templates:

```

C ::= '$ALL' | '$NONE' | cname | C ',' C |
      C ';' C | '$not' C | D |
      '{' [ iname  $\rightarrow \alpha$  ] { ',' , iname  $\rightarrow \alpha$  } ] '}' |
      C '(' D ')' | '(' C ')' |
      CW | C '['  $\geq \alpha$  ']' | C '['  $\leq \alpha$  ']' |
      DT | M '(' C ')'

CW ::= C  $\rightarrow \alpha$  | CW + CW

DT ::= crisp('N', 'N') | l('N', 'N') |
      r('N', 'N') | M
  
```



Semantic and fuzziness in TuCSoN

Fuzzy semantic templates

- A fuzzy SHOIN(D)-like description language for templates:

```

M ::= triangular('N','N','N') |
    trapezoidal('N','N','N','N')

D ::= F | '$exists' F | '$all' F | M

F ::= R 'in' C | R ':' I | R ':' I | R ':' Msymb N |
    R ':' '=' string | R

M ::= '#' R Msymb N

R ::= rname | rname '/' vname

Msymb ::= '>' | '<' | '≥' | '≤' | '='
  
```

Example:

'Car' ((hasMaxSpeed:280 $\rightarrow$ 0.6) + (hasMaker:ferrari $\rightarrow$ 0.4))



Semantic and fuzziness in TuCSoN

Tuple matching

- Fuzzy semantic matching mechanism amounts to look for the fuzzy individuals which are instances of the given fuzzy concept, namely, which tuples match the template.
- Fuzzy Description Logic reasoners like DeLorean [3] can be used to perform this kind of reasoning.



Semantic and fuzziness in TuCSoN

Tuple space primitives

- In a semantic view, tuple space primitives (in, rd, and out) represent the language whereby system components can read, consume, and write knowledge described by means of a domain ontology.
 - Each primitive can fail in case of non-consistency with the ontology.
- ⇒ Differently from the original tuple space semantic, the **out** can fail in case the related tuple is not consistent with the domain ontology.
- In face of a fuzzy template, it is needed too return a fuzzy tuple along with the degree by which it satisfies the template, since this could be different from 1.



Semantic and fuzziness in chemical tuple spaces

Example

We consider a scenario of advertisements for cars:

- Example law: $(\text{SportCar} \rightarrow 0.8; (\text{hasMaker}:\text{audi} \rightarrow 0.2)) \xrightarrow{r} 0$
- Candidate tuple gives 0.72:
f380: 'SportCar' $\rightarrow$ 0.9 (hasMaker : ferrari,
hasMaxSpeed : '320km/h', hasColour : red)
- The global rate of the reaction instance is $r \times \#f380 \times 0.72$



Future work

Further research and development about

- Match factor
- Performance
- Chemical language
- Application cases

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