

Distributed Planning and Model Learning for Urban Traffic Control

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KEPS Workshop



Traffic Problem



Controlling Traffic



Controlling Traffic



- **Split:** green and red time
- **Phase:** junction coordination
- **Offset:** inter-junction coordination → green waves

$$\begin{aligned}x_z(k+1) &= x_z(k) + p_z^x(k) + T((1 - \kappa_z)g_z(k) - h_z(k)) \\ &+ Td_z(k) + p_z^d(k) = (1 + \delta_z^x(k)\gamma_z^x)x_z(k) \\ &+ T((1 - \kappa_z)g_z(k) - h_z(k)) \\ &+ (1 + \delta_z^d(k)\gamma_z^d)Td_z(k)\end{aligned}$$

$$\begin{aligned}\min_{\mathbf{u}, t, \tau} \quad & t \\ \text{s.t.} \quad & \begin{pmatrix} t & \tilde{\mathbf{x}}^T & \mathbf{u}^T & \Psi^T \\ \tilde{\mathbf{x}} & \mathcal{Q}^{-1} - \Lambda\mathcal{T}\Lambda^T & 0 & -\Lambda\mathcal{T}\Omega^T \\ \mathbf{u} & 0 & \mathcal{R}^{-1} & 0 \\ \Psi & -\Omega\mathcal{T}\Lambda^T & 0 & \mathcal{T} - \Omega\mathcal{T}\Omega^T \end{pmatrix} \succeq 0\end{aligned}$$

(Tettamanti *et al.*, 2014)

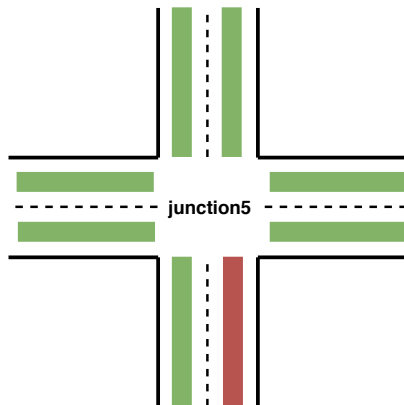
- Handmade static programs
- Static systems optimized with historic data: **TRANSYT** (Robertson, 1969)
- Dynamic systems: **SCOOT** (Bretherton *et al.*, 1998)

- Neural networks (Box *et al.*, 2012)
- Reinforcement learning (Jin *et al.*, 2017)
- Scheduling **SURTRAC** (Xie *et al.*, 2012) **working!**
- **Automated Planning** (Pozanco *et al.*, 2016; Gulic *et al.*, 2016; Vallati *et al.*, 2016)

Automated Planning for UTC

IAS (Gulic *et al.*)

- **State** → static and dynamic state of the city
- **Goals** → achieve low density in congested streets
- **Actions** → set traffic lights to green at each junction



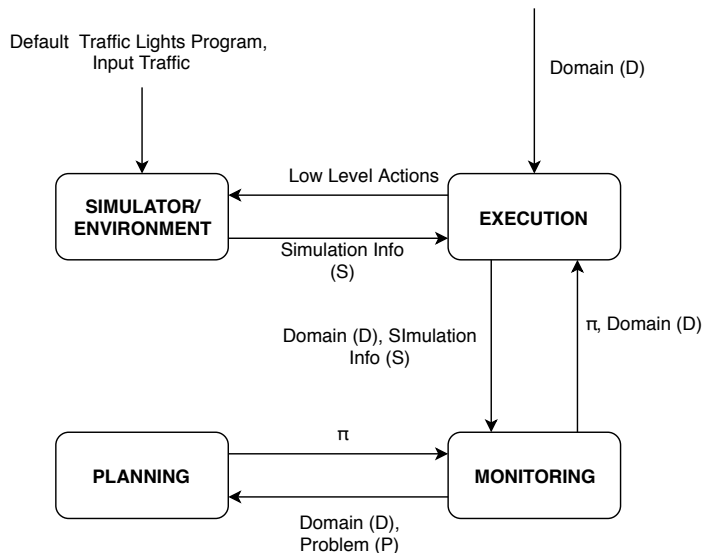
Action

```
(:action one-high
:parameters (?c - junction ?sin1 - street ...
             ?sout1 - street ...)
:precondition (and (goes-into ?sin1 ?c)
                  (in-front-of ?sin1 ?sin3)
                  ...
                  (goes-out ?sout4 ?c)
                  (not (= ?sin1 ?sin2))
                  (densityLevel ?sin1 high)
                  (densityLevel ?sin3 low)...))
:effect (and (densityLevel ?sin1 low)
             (not (densityLevel ?sin1 high))
             (densityLevel ?sin3 low)
             (not (densityLevel ?sin3 high))))
```

Problem

```
(define (problem traffic1) (:domain traffic)
  (:objects sin1 ... sout7 - street
           j1 j2 - junction)
  (:init (goes-into sin1 j1)
         (in-front-of sin1 sin3)
         (densityLevel sin1 high)
         (densityLevel sin2 low)...)
  (:goal (and (densityLevel sin1 low)
              (densityLevel sin3 low)
              (densityLevel sout7 low) ...)))
```

IAS Architecture



Planning Drawbacks

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- Knowledge engineering effort
 - Models do not fit the real scenario
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 - Number of streets and traffic lights
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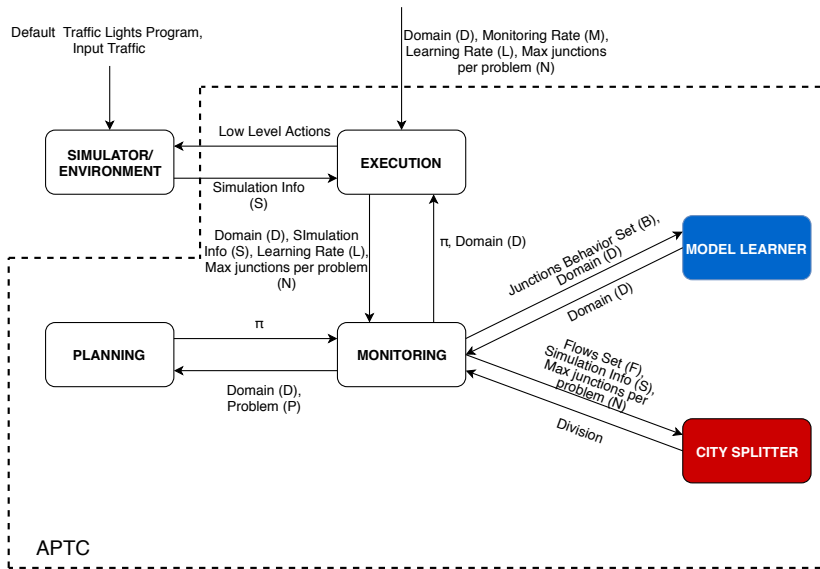
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IAS DRAWBACKS

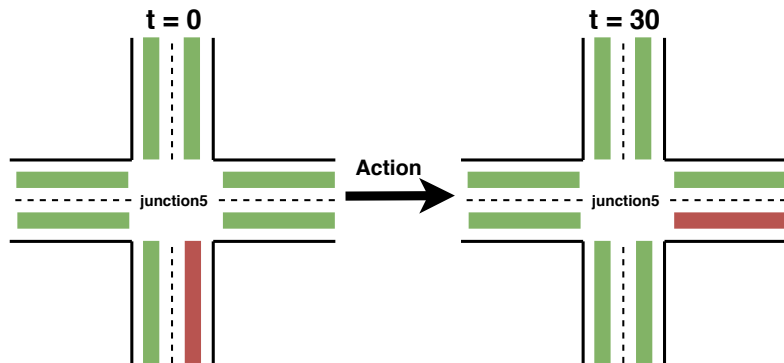
- Unsolvable congestions
 - Unsolvable planning task
 - No actions are returned by the system

APTC Architecture



Model Learner

Junction Behavior Table

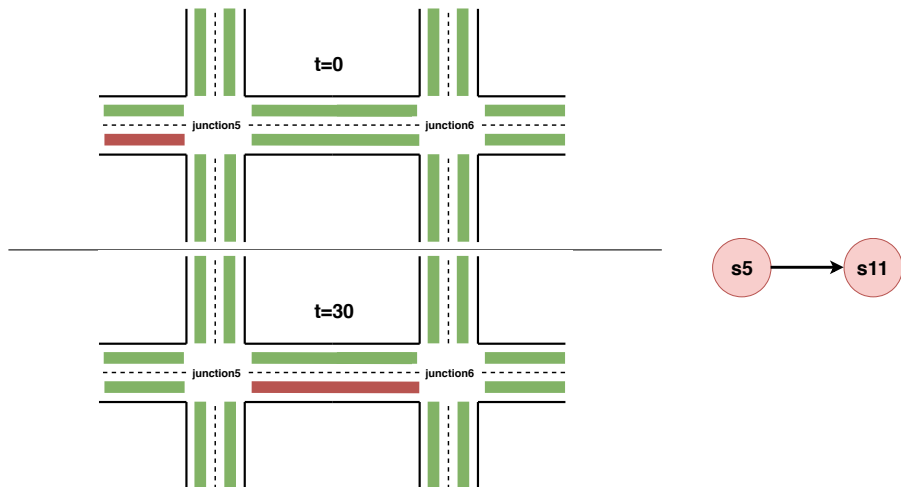


action	pre-state	post-state	frequency
oneHigh	h- - - - - - - - - -	- - - - - - - - - -	54
oneHigh	h- - - - - - - - - -	- - - - - - - - - -	27
oneHigh	- - - - - - - - - -	- - - - - - - - - -	10
twoHighInFront	h- - - - - - - - - -	- - - - - - - - - -	32
twoHighInFront	h- - - - - - - - - -	- - - - - - - - - -	66

Learned Action

```
(:action J6-twoHighIF-h-l-h-l-l-l-l-l-l
:parameters ()
:precondition (and (goes-into sin1 j6)
                  (goes-out sout4 j6)
                  (densityLevel sin1 high)
                  (densityLevel sout4 low)
                  ...))
:effect (and (densityLevel sin1 low)
            (not (densityLevel sin1 high))
            (densityLevel sout1 high)
            (not (densityLevel sout1 low))
            ...))
```

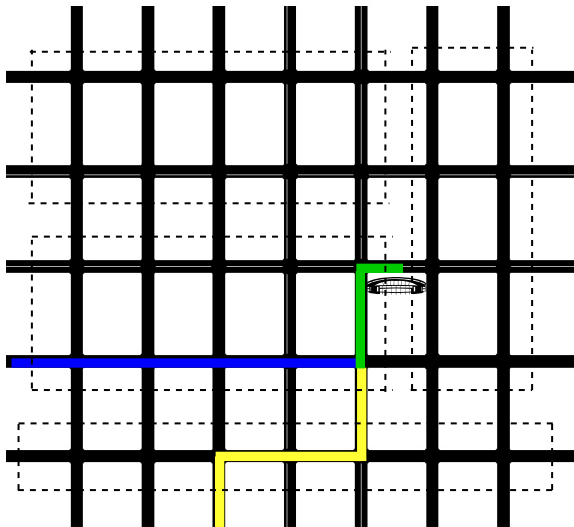
City Splitter



- Maximum length disjoint paths
- Balance the number of junctions on each problem

City Splitter

Splitting city example



Summarizing

$M=30$

$U,S=300$

```
1: while simulation-step  $\leq T$  do
2:   if simulation-step mod( $M$ ) = 0 then
3:     Flows, JunctionBehaviorTables = MONITORING(D,P,K)
4:     if simulation-step mod( $U$ ) = 0 then
5:       D = MODEL-LEARNER(JunctionBehaviorTables)
6:     if simulation-step mod( $S$ ) = 0 then
7:       P = CITY-SPLITTER(Flows)
8:     Plan = PLANNING(D,P)
9:     EXECUTION(Plan)
10:    simulation-step += 1
```

Evaluation

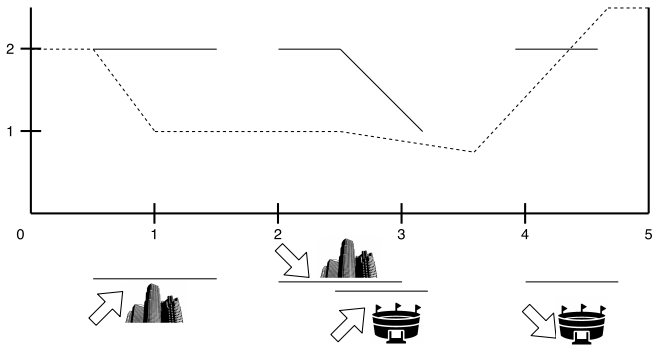
Experimental Setting

SUMO traffic simulator



Evaluation

Experimental Setting



- 100 junctions
- 5 hours

Compared Systems

- **STATIC:** default SUMO configuration
- **REACTIVE:** SCOOT simplification without offsets
- **IAS:** starting approach
- **FIXED:** starting approach + oversubscription
- **APTC:** starting approach + oversubscription + action's learning

Measured metrics

- CO_2 : in kg
- AWT: Average waiting time (seconds)
- ATT: Average travel time (seconds)
- DC: % of cars in destination

Total simulation results

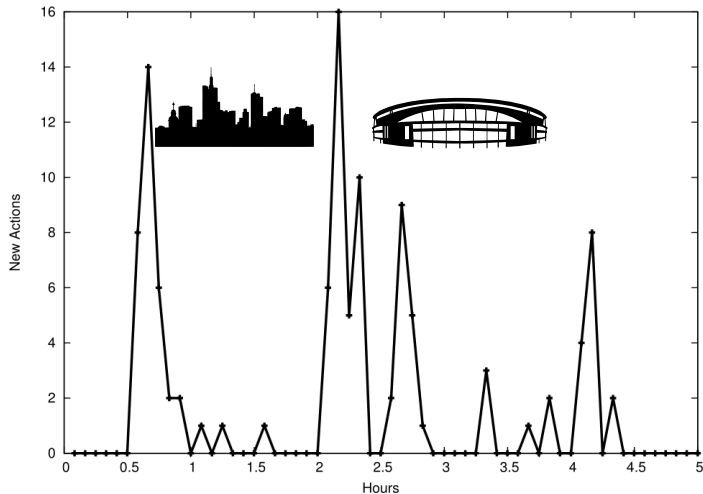
	$C0_2$	AWT	ATT	DC
STATIC	2972	120	188	94%
REACTIVE	-2%	-15%	-7%	95%
IASMANUAL	-1%	-13%	-5%	95%
IASFLOWS	-3%	-16%	-13%	96%
FIXEDMANUAL	-4%	-21%	-15%	97%
FIXEDFLOWS	-7%	-25%	-16%	98%
APTCMANUAL	-11%	-30%	-18%	99%
APTCFLOWS	-13%	-33%	-20%	100%

- APTC > FIXED
- FLOWS > MANUAL

Evaluation

Learning results

APTC's adaptation to changes



- Declarative system

Wrapping up

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 - Quick problem solving

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 - Quick problem solving
 - Flows-based splitting criteria > Manual splitting

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