# AI Planning

## 4. Applications

## A Few Problems We Can Solve (and Which Some People Care About)

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Thanks to Prof. Jörg Hoffmann for slide sources

# Agenda

# Motivation

*. . . well, does anybody need to be motivated?*

→ I'm presuming that "Applications" sounds better than "The expressive power of merge-and-shrink abstractions" . . .

**Applications are important:**

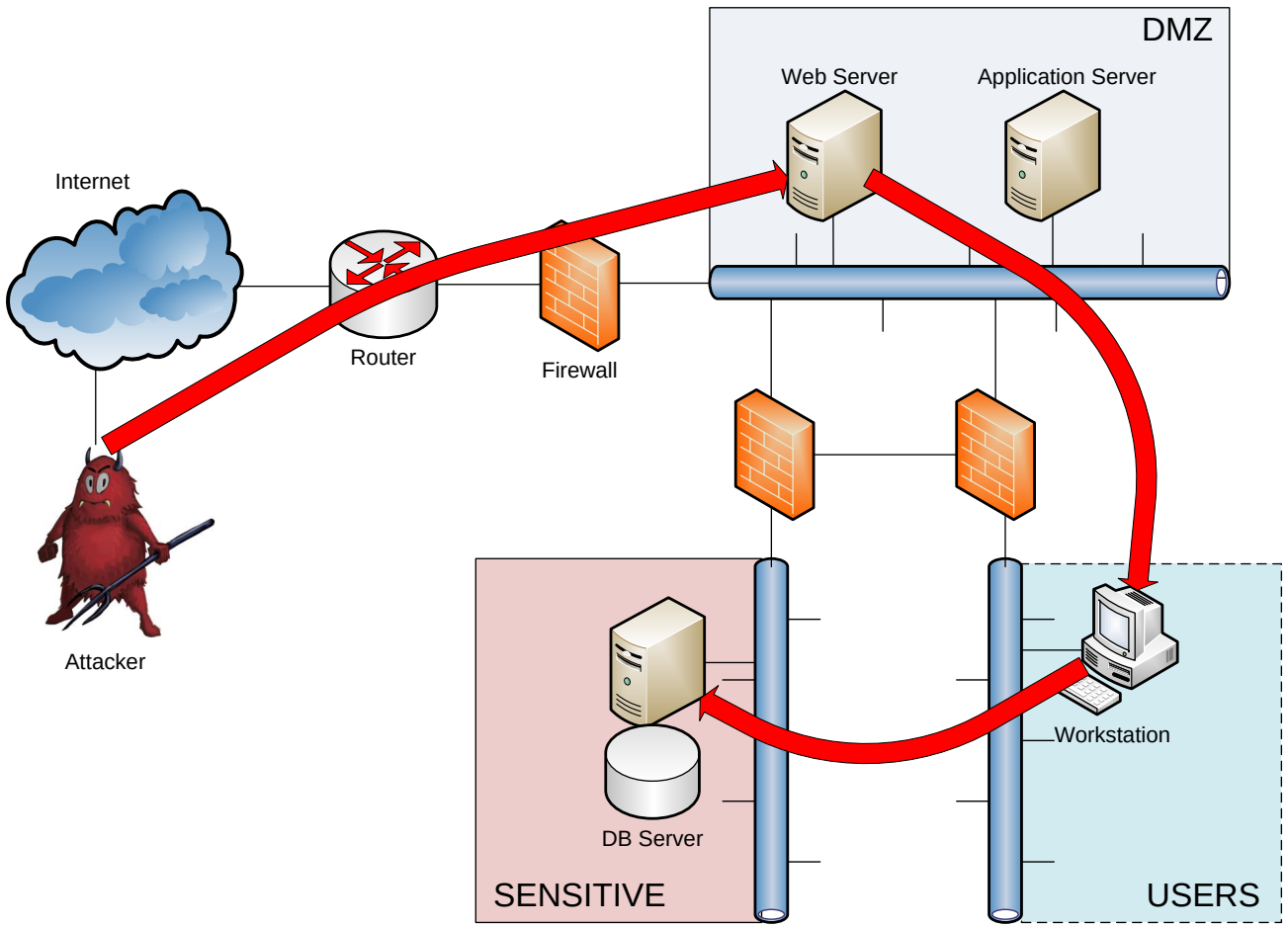
- Validate research ideas and techniques.
- Source of new research problems to consider.
- Source of useful benchmark examples to evaluate algorithms.

→ **FAI BSc/MSc/HiWi Jobs:** All three application areas here are major ongoing/future research efforts in FAI.

# Our Agenda for This Chapter

2. **Simulated Penetration Testing:** Simulating hackers (well, simple versions thereof) for automated network security testing.
3. **Natural Language Generation:** Turning a language grammar and an intended meaning into a sentence.
4. **Modular Printing System Control:** How to control all printers that could possibly be built.

# Network Hacking



# Penetration Testing (Pentesting)

## Pentesting

Actively verifying network defenses by conducting an intrusion in the same way an attacker would.

- Well-established industry (roots back to the 60s).
- Points out specific dangerous attacks (as opposed to vulnerability scanners).
- Pentesting tools sold by security companies, like Core Security.
  $\rightarrow$ Core IMPACT (since 2001); Immunity Canvas (since 2002); Metasploit (since 2003).
- Run security checks launching exploits.
- Core IMPACT uses FF (cf. **Chapter 9**) for automation since 2010.

# Motivation for Automation

# Motivation for Automation: Wrap-Up

**Simulated penetration testing serves to:**

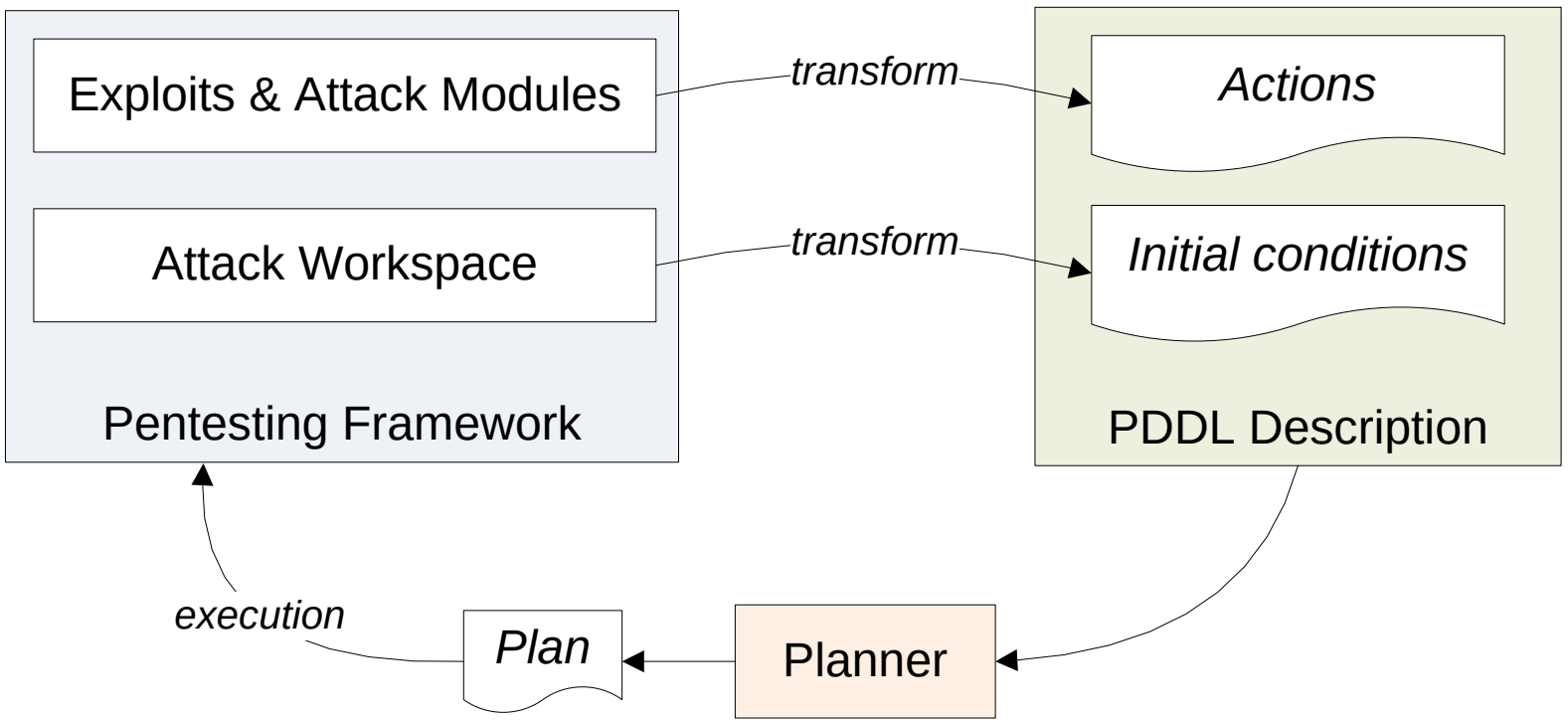
- Reduce human labor.
- Increase testing coverage:
  - Higher testing frequency.
  - Broader tests trying more possibilities.
- Deal with the dynamics of pentesting:
  - More exploits.
  - New tools used in attacks (Client-Side, WiFi, WebApps, ...).

$\rightarrow$ The aim is to automate pentesting, so that the attacks can continuously be run in the background, thus decreasing human labor while allowing broad coverage of complex attack possibilities.

# The Turing Test, Revisited

# Simulated Pentesting at Core Security

**Core IMPACT system architecture:**




→ In practice, the attack plans are being used to point out to the security team where to look.

# Core Security PDDL

**Object Types:**

| | |
|---|---|
| network | operating_system |
| host | OS_version |
| port | OS_edition |
| port_set | OS_build |
| application | OS_servicepack |
| agent | OS_distro |
| privileges | kernel_version |

# Core Security PDDL, ctd.

**Predicates expressing connectivity:**

```
(connected_to_network ?s - host ?n - network)
(IP_connectivity ?s - host ?t - host)
(TCP_connectivity ?s - host ?t - host ?p - port)
(TCP_listen_port ?h - host ?p - port)
(UDP_listen_port ?h - host ?p - port)
```

# Core Security PDDL, ctd.

**Predicates expressing configurations:**

```
(has_OS ?h - host ?os - operating_system)
(has_OS_version ?h - host ?osv - OS_version)
(has_OS_edition ?h - host ?ose - OS_edition)
(has_OS_build ?h - host ?osb - OS_build)
(has_OS_servicepack ?h - host ?ossp - OS_servicepack)
(has_OS_distro ?h - host ?osd - OS_distro)
(has_kernel_version ?h - host ?kv - kernel_version)
(has_architecture ?h - host ?a - OS_architecture)
(has_application ?h - host ?p - application)
```

# Core Security PDDL, ctd.

**Actions modeling exploits:**

```
(:action HP_OpenView_Remote_Buffer_Overflow_Exploit
:parameters (?s - host ?t - host)
:precondition (and (compromised ?s)
  (and (has_OS ?t Windows)
    (has_OS_edition ?t Professional)
    (has_OS_servicepack ?t Sp2)
    (has_OS_version ?t WinXp)
    (has_architecture ?t I386))
  (has_service ?t ovtrcd)
  (TCP_connectivity ?s ?t port5053)
)
:effect(and (installed_agent ?t high_privileges)
  (increase (time) 10)
))
```

# Core Security PDDL, ctd.

**Actions allowing to reap benefits of exploits:**

```
(:action Mark_as_compromised
:parameters (?a - agent ?h - host)
:precondition (installed ?a ?h)
:effect (compromised ?h)
)

(:action IP_connect
:parameters (?s - host ?t - host)
:precondition (and (compromised ?s)
  (exists (?n - network)
    (and (connected_to_network ?s ?n)
      (connected_to_network ?t ?n))))
:effect (IP_connectivity ?s ?t)
)
```

# Core Security PDDL, ctd.

**An attack plan:**

```
 0: Mark_as_compromised localagent localhost
 1: IP_connect localhost 10.0.1.1
 2: TCP_connect localhost 10.0.1.1 port80
 3: Phpmyadmin Server_databases Remote Code Execution
        localhost 10.0.1.1
 4: Mark_as_compromised 10.0.1.1 high_privileges
 ...
14: Mark_as_compromised 10.0.4.2 high_privileges
15: IP_connect 10.0.4.2 10.0.5.12
16: TCP_connect 10.0.4.2 10.0.5.12 port445
17: Novell Client NetIdentity Agent Buffer Overflow
        10.0.4.2 10.0.5.12
18: Mark_as_compromised 10.0.5.12 high_privileges
```

# Simulated Pentesting@Core Security: Remarks

**History:**

- Planning domain "of this kind" (less IT-level, including also physical actions like talking to somebody) first proposed by [Boddy *et al.* (2005)]; used as benchmark in IPC'08 and IPC'11.
- Presented encoding proposed by [Lucangeli *et al.* (2010)].
- Used commercially by Core Security in Core INSIGHT since 2010.

**Do Core Security's customers like this?**

- I am told they do.
- In fact, they like it so much already that Core Security is very reluctant to invest money in making this better ...

# Questionnaire

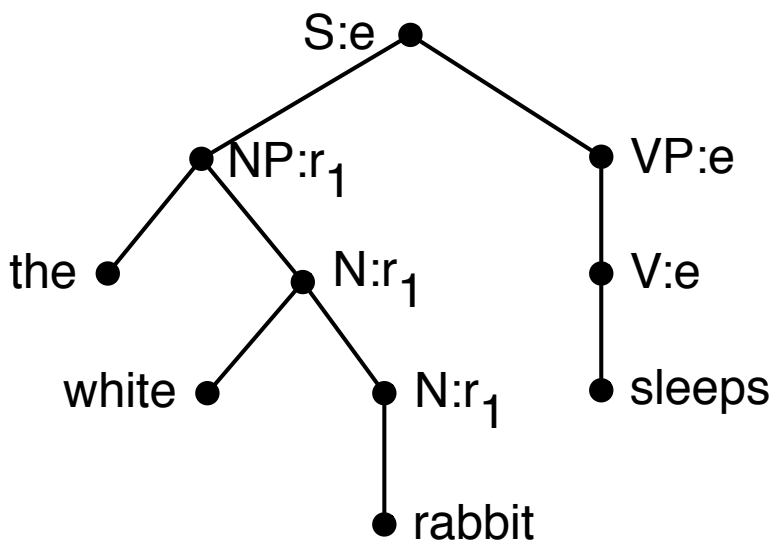
## Question!

**Is the current realization @Core Security really a simulation of what human hackers do?**

(A): Yes. (B): No.

# Research → FAI BSc/MSc/HiWi; Cooperation CISPA

# Natural Language Generation (NLG)




- **Input:** Grammar, intended meaning.
- **Output:** Sentence implementing meaning.

# NLG as Planning, Remarks

**Historical:**

- Long-standing historical connection between NLG and Planning (first mentioned in early 80s).
- Resurrected in 2007, after long silence, thanks to efficiency of heuristic search planners like FF [Hoffmann and Nebel (2001)] → **Chapter 9**.
- Encoding below proposed by [Koller and Stone (2007)].
- Used here in SB at M2CI. (See the "Video Documentary" at `http://www.mmci.uni-saarland.de/en/start`, min. 1:38 – 1:46)

**Main advantages of planning in this application:**

- Rapid development (try to develop a language generator yourself . . . ).
- Flexibility (grammar/knowledge changes handled automatically).

# NLG with TAG

**NLG in General:**

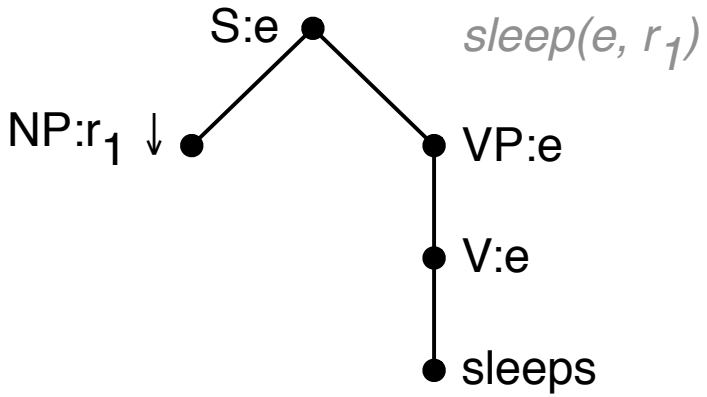
- Given semantic representation (formula) and grammar, compute sentence that expresses this semantics.
- Standard problem in natural language processing, many different approaches exist.

**NLG here:**

- NLG with tree-adjoining grammars (TAG) [Koller and Stone (2007)].
- Grammar given in form of finite set of elementary trees.
- Problem instance given by grammar, knowledge base, and a set of ground atoms which the sentence should express.

# NLG with TAG: Example

**Task:** Express ground atom $\{sleep(e, r_1)\}$.
**Knowledge Base:** $\{sleep(e, r_1),\ rabbit(r_1),\ white(r_1),\ rabbit(r_2)\}$.




- "S:e" stands for sentence referring to event $e$.
- "NP:$r_1$ $\downarrow$" stands for a noun phrase referring to $r_1$, which must be substituted here.
- ["VP:e" and "V:e" stand for a verb phrase referring to $e$, and can be used to adjoin further trees (not detailed here).]

# NLG with TAG: Example, ctd.

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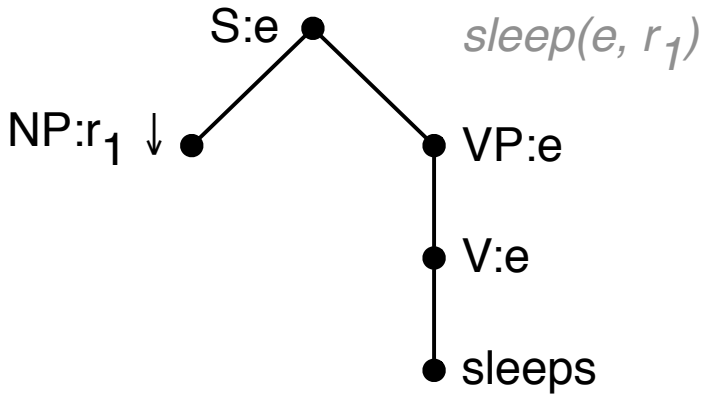


- Is this a complete sentence derivation?

# NLG with TAG: Example, ctd.

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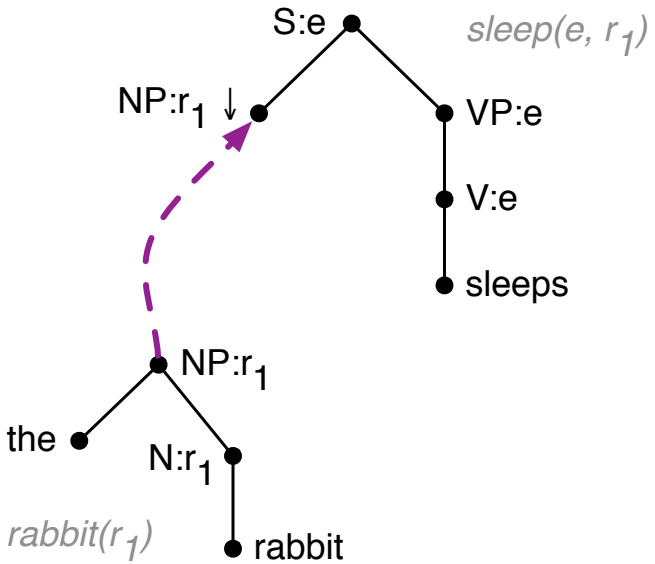


- This is a substitution operation (purple dashed arrow in our illustration).
- "N:$r_1$" stands for a noun-phrase element referring to $r_1$, and can be used to adjoin further trees.

# NLG with TAG: Example, ctd.

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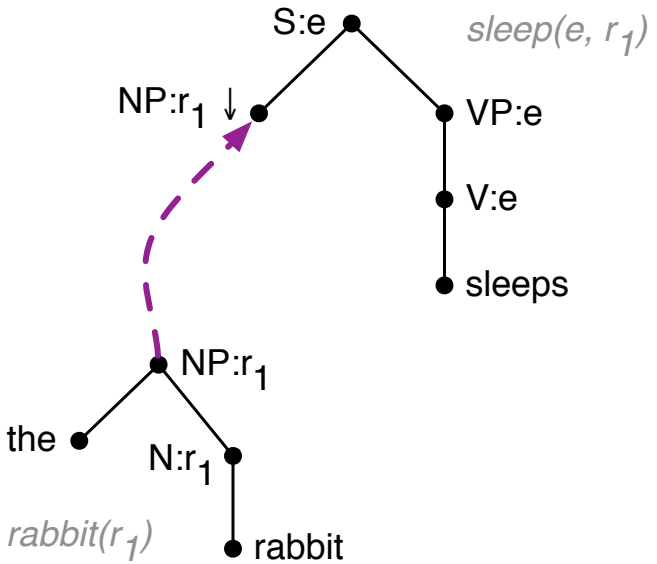


- Is this a complete sentence derivation?
- Does the sentence express the desired meaning?

# NLG with TAG: Example, ctd.

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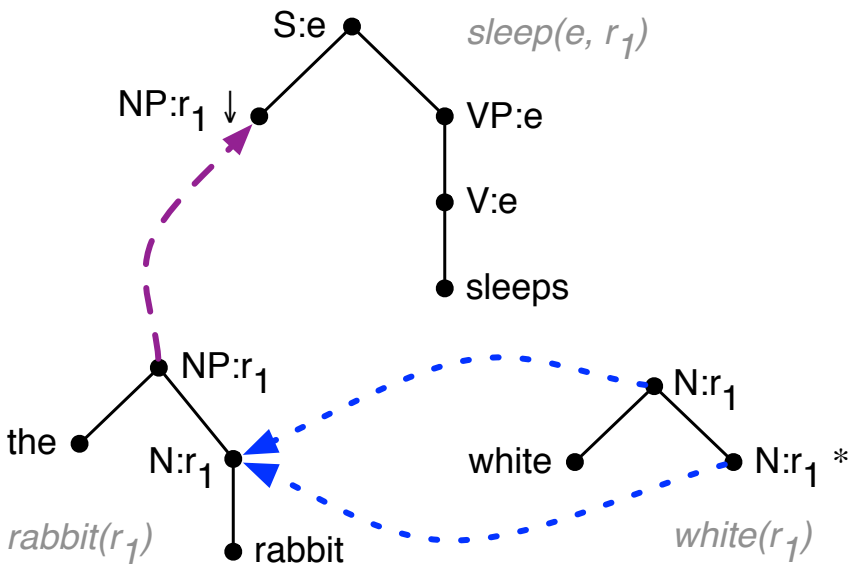


- This is an adjunction operation (blue dotted arrow in our illustration).
- "N:$r_1$" stands for a noun-phrase element referring to $r_1$, and can be used to adjoin further trees.

# NLG with TAG: Example, ctd.

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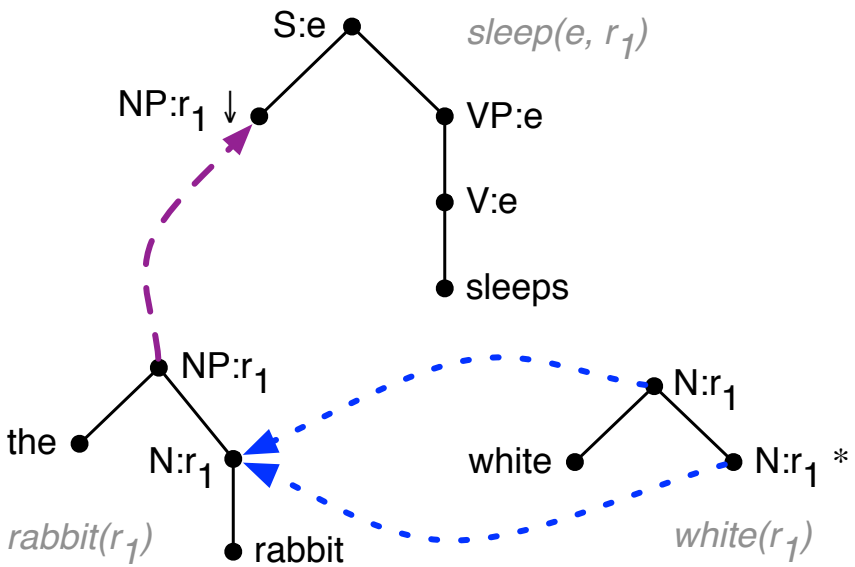
**Knowledge Base:** $\{sleep(e, r_1),\ rabbit(r_1),\ white(r_1),\ rabbit(r_2)\}$.

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# NLG with TAG: Example, ctd.

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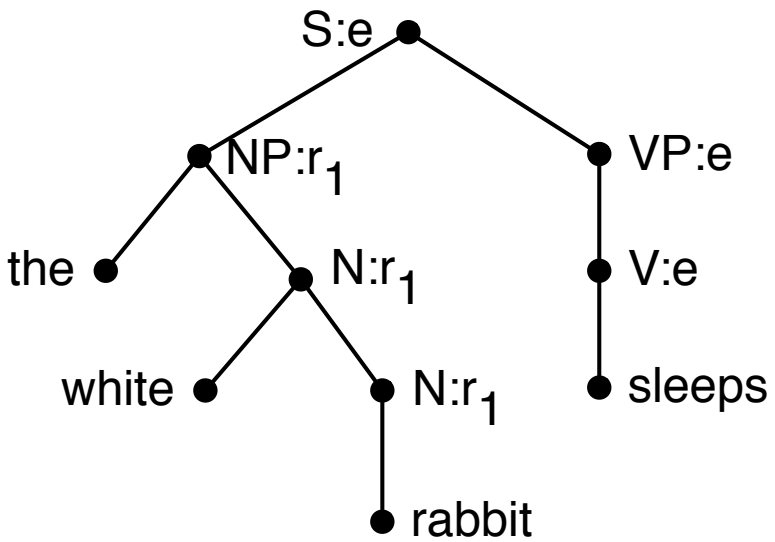



- The outcome of our substitution and adjunction operations here.
- To obtain the desired sentence, read off the leaves from left to right.

# . . . and now in PDDL!

From [Koller and Hoffmann (2010)], slightly simplified:

**sleeps**$(u, u', x, x')$**:**
*pre:* $subst(S, u)$, $ref(u, x)$, $sleep(x, x')$
*eff:* $expressed(sleep, x, x')$, $\neg subst(S, u)$, $subst(NP, u')$, $ref(u', x')$, $\forall y.y \neq x' \rightarrow distractor(u', y)$

"$u, u'$": nodes in grammar trees
"$x$": event
"$x'$": sentence subject

**rabbit**$(u', x')$**:**
*pre:* $subst(NP, u')$, $ref(u', x')$, $rabbit(x')$
*eff:* $\neg subst(NP, u')$, $canadjoin(N, u')$, $\forall y.\neg rabbit(y) \rightarrow \neg distractor(u', y)$

**white**$(u', x')$**:**
*pre:* $canadjoin(N, u')$, $ref(u', x')$, $white(x')$

*eff:* $\forall y.\neg white(y) \rightarrow \neg distractor(u', y)$

Initial state: $subst(S, u_0)$, $ref(u_0, e)$, $sleep(e, r_1)$, $rabbit(r_1), \ldots$

Goal: $expressed(sleep, e, r_1)$
$\forall u \forall x.\neg subst(u, x)$
$\forall u \forall x.\neg distractor(u, x)$

Plan: $\langle$**sleeps**$(u_0, u_1, e, r_1)$, **rabbit**$(u_1, r_1)$, **white**$(u_1, r_1)\rangle$.

# Questionnaire

## Question!

**In the action "sleeps$(u, u', x, x')$" in our NLG problem instance, what for do we need the effect literal "$\neg subst(S, u)$"?**

(A): So we don't fall asleep.

(B): So the rabbit does not fall asleep.

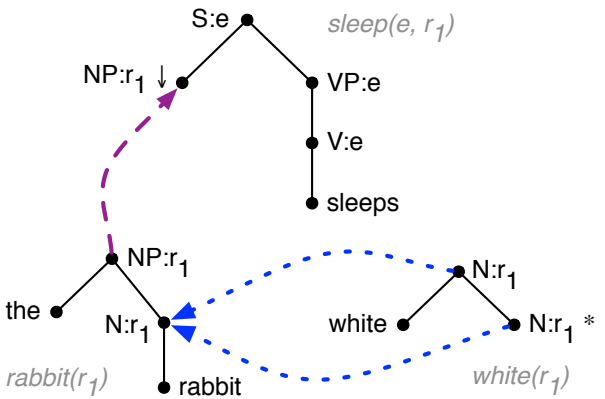
(C): To mark the subject of $S$ as being open.

(D): To mark $S$ itself as closed.

**sleeps**$(u, u', x, x')$:

*pre:* $subst(S, u)$, $ref(u, x)$, $sleep(x, x')$

*eff:* $expressed(sleep, x, x')$, $\neg subst(S, u)$, $subst(NP, u')$, $ref(u', x')$, $\forall y.y \neq x' \rightarrow distractor(u', y)$



# Questionnaire, ctd.

## Question!

**When we apply the action "sleeps$(u, u', e, r_1)$" in our NLG problem instance, what does "$u'$" stand for?**

(A): The verb phrase.

(B): The noun phrase.

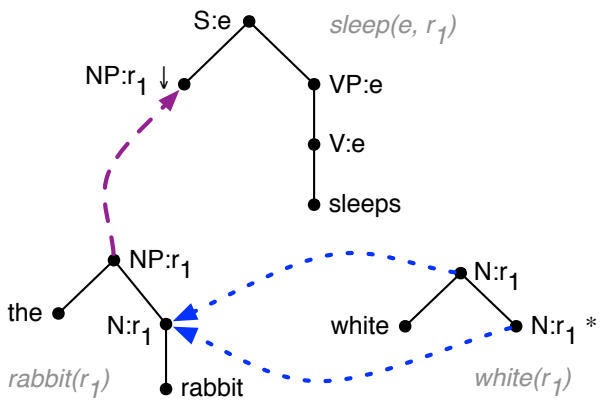
(C): The node "NP:$r_1 \downarrow$" in the verb-phrase tree.

(D): The tree representing the noun phrase.

**sleeps**$(u, u', x, x')$:

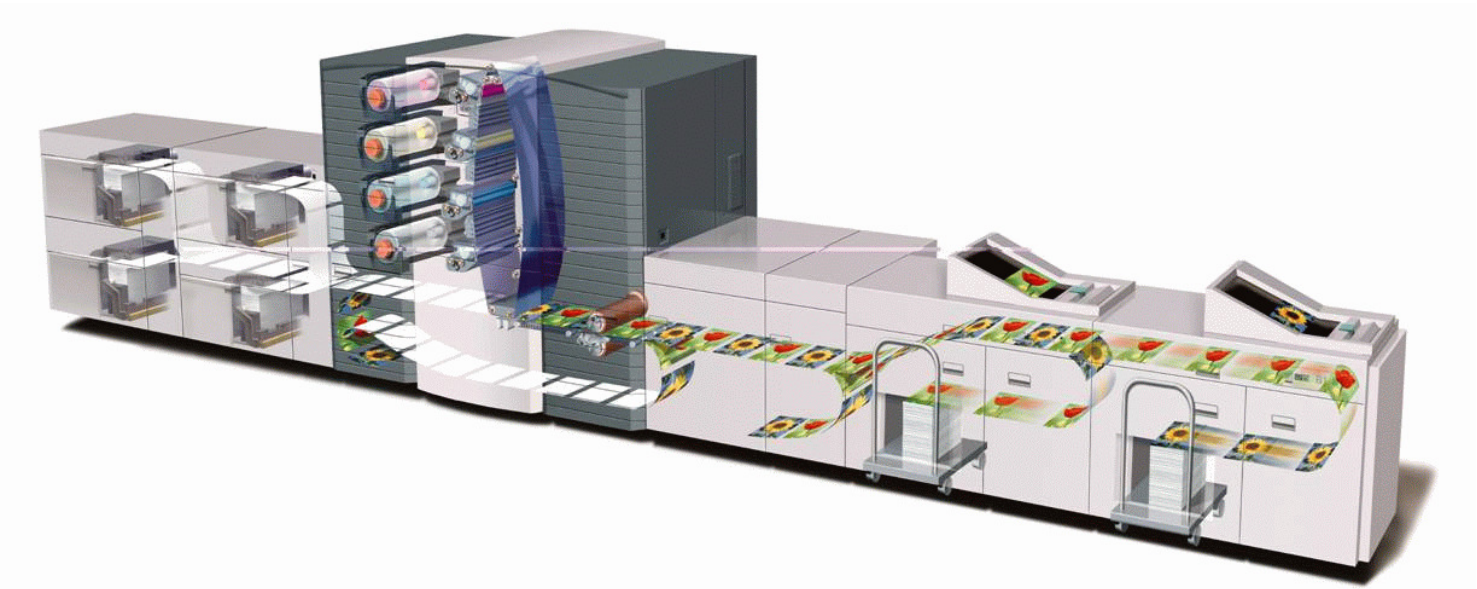
*pre:* $subst(S, u)$, $ref(u, x)$, $sleep(x, x')$

*eff:* $expressed(sleep, x, x')$, $\neg subst(S, u)$, $subst(NP, u')$, $ref(u', x')$, $\forall y.y \neq x' \rightarrow distractor(u', y)$



# Research → FAI BSc/MSc/HiWi; Cooperation CoLi

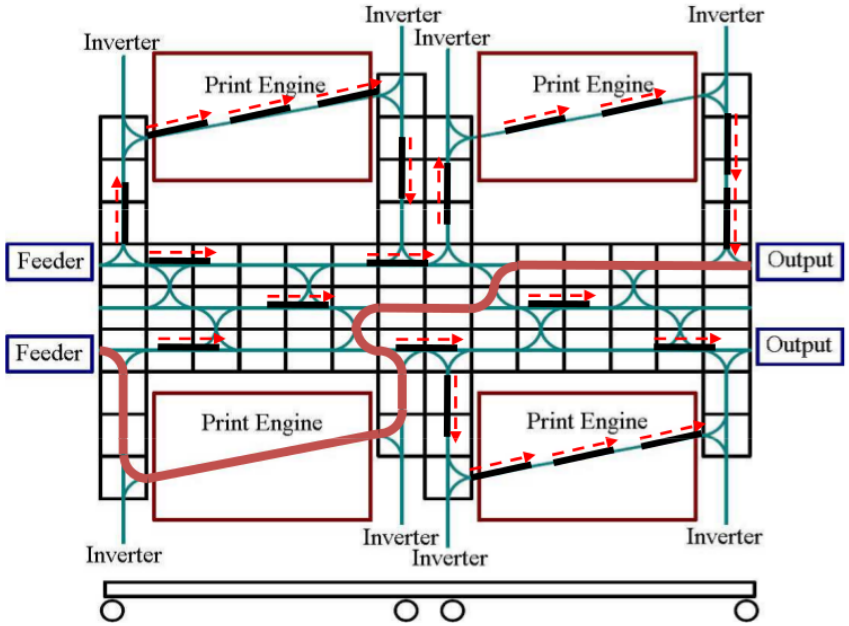
# Large-Scale Printing Systems: Complex stuff already . . .



- Process blank sheets of paper into anything (book/bill in folded envelope, . . . ).
- Hundreds of independently controlled processing components.
- Dozens of different processes active at any one time.
- Online problem, new jobs come in as we go.

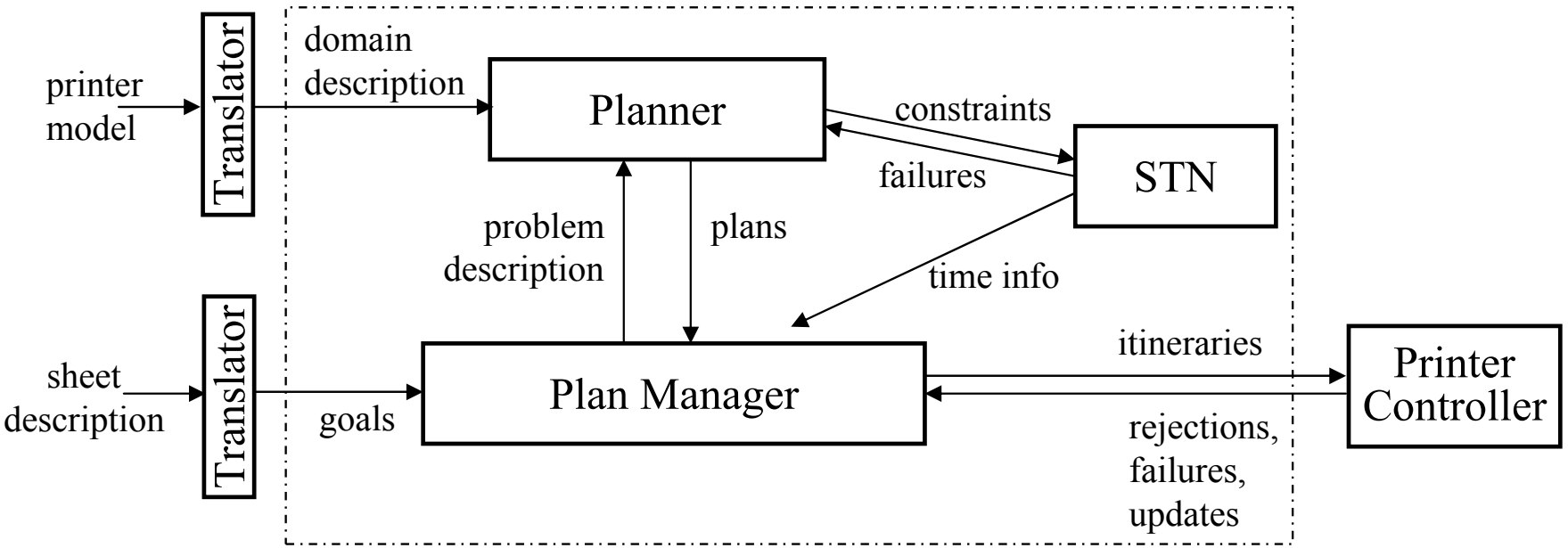
# . . . and now we're making it MUCH worse!

**MODULAR Large-Scale Printing Systems:**



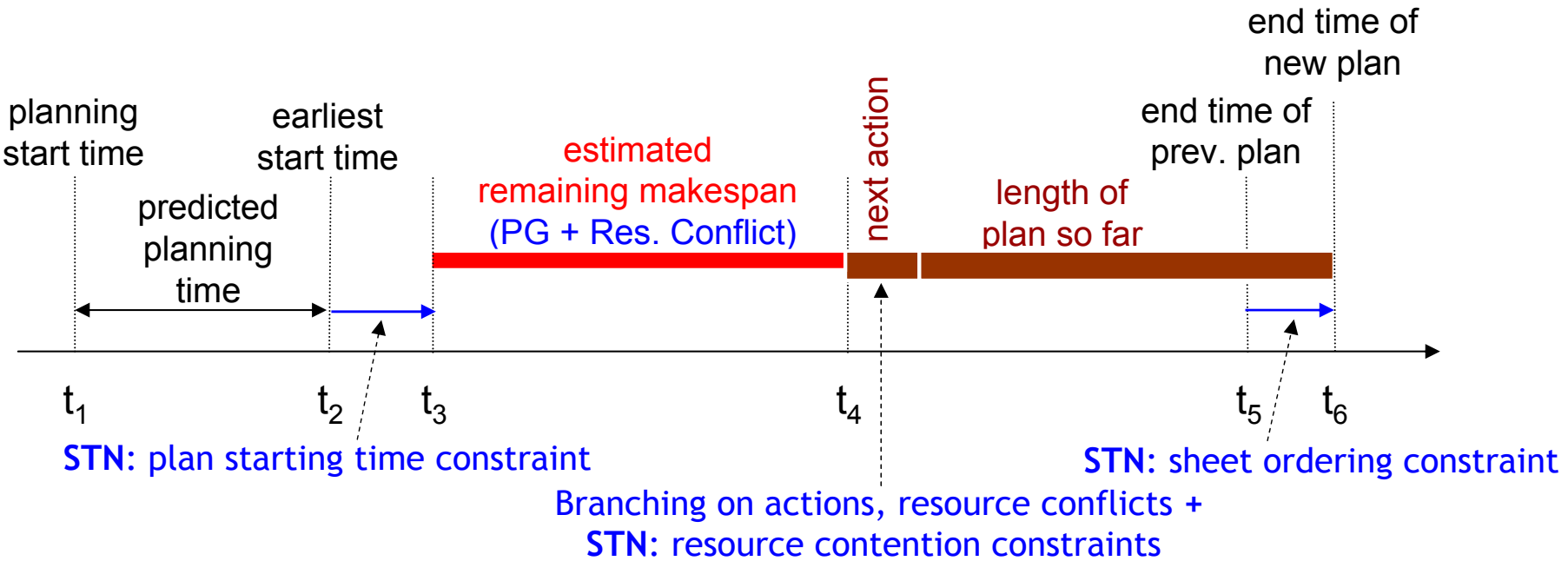

- Assemble and configure components as required by customer.
- No need to buy stuff you don't want, easy to adapt as needed.
- Control can no longer be pre-programmed/configured for a particular machine.
- Requires flexible software that can control anything we could build!

# Planning To the Rescue!



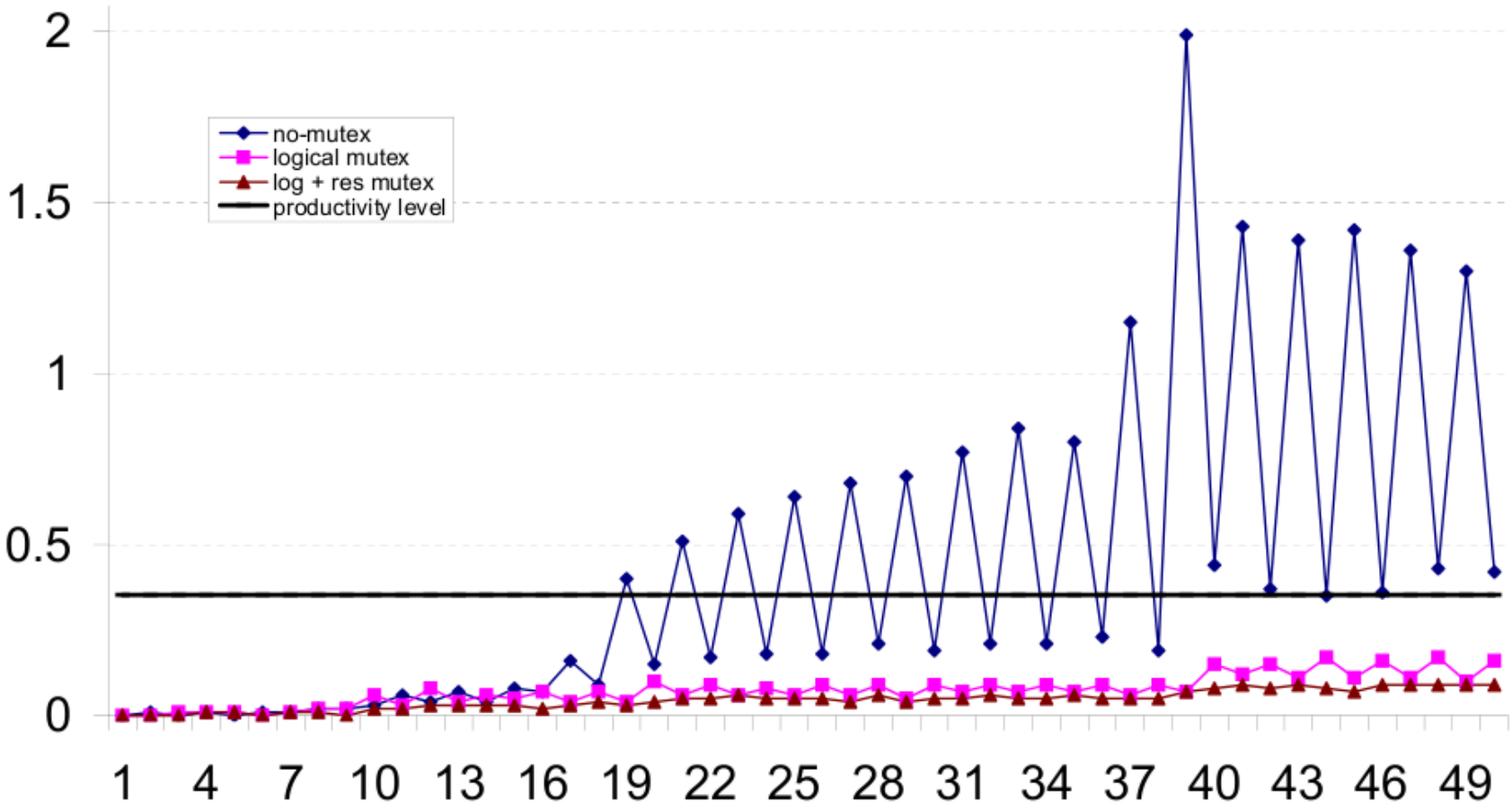

- "Planner" as opposed to "Plan Manager": Finding a solution for the task at any given point in time, vs. managing the updates to the task (new jobs arriving, job cancelled due to paper jam, ...).
- "STN": Simple Temporal Network. A constraint-based representation of action durations and precedence constraints, identifying unresolvable conflicts.
- The rest should be self-explanatory ...

# Planning To the Rescue! Ctd.




- Regression search → **Chapter 6** using $A^*$ → **Chapter 7**.
- Heuristic function: A temporal variant of $h^2$ ("PG" here is for "planning graph") → **Chapter 8**.
- "Planning start time", "predicted planning time", "plan starting timing constraint", "resource conflicts", "resource contention constraints", "end time of prev./new plan": Relate to online/temporal aspects of domain.

# Empirical Performance




- $x$-axis: jobs come in during online processing; $y$-axis: runtime (seconds) for planning the new job; productivity level: runtime needed for practicability.
- "no mutex": without $h^2$ heuristic function.
  $\rightarrow$ $h^2$ is the key element making this work!

# Research → FAI BSc/MSc/HiWi; Cooperation DFKI

# Summary

- Thanks to the efficiency of heuristic search planning techniques, planning is being applied in a broad variety of applications today.
- Simulated penetration testing is used for regular network security checks, and is commercially employed with FF as the underlying planner.
- Natural language generation involves constructing sentences, and can be successfully encoded into PDDL using FF.
- Flexible printer system control is required for large-scale configurable printing systems, and can be successfully tackled using a temporal variant of the planning heuristic $h^2$.

# Remarks

There's quite a range of **further application areas:**

- Greenhouse logistics involves moving a series of conveyor belts to cater for the needs of all the plants [Helmert and Lasinger (2010)].
- Plan recognition involves observing (some of) the actions of an agent, and inferring what the goal is [Ramírez and Geffner (2009)].
- Business process management involves creating, maintaining, and executing complex processes across large enterprises; planning can be used to automatically generate process templates [Hoffmann *et al.* (2012)].
- Software model checking involves (amongst others) finding bugs; this can be formulated as finding a plan to an error state [Kupferschmid *et al.* (2006)].

# Reading

- *Simulated Penetration Testing: From "Dijkstra" to "Turing Test++"* [Hoffmann (2015)].

  Available at:

  `http://fai.cs.uni-saarland.de/hoffmann/papers/icaps15inv.pdf`

  Content: Overview of simulated pentesting models, systematization of framework with respect to possible models of uncertainty, and with respect to the complexity of the action models considered.

# Reading

- *Waking Up a Sleeping Rabbit: On Natural-Language Sentence Generation with FF* [Koller and Hoffmann (2010)].

  Available at:

  `http://fai.cs.uni-saarland.de/hoffmann/papers/icaps10.pdf`

  Content: Summarizes the NLG problem based on TAG, and its encoding into PDDL. Gives a compact summary of the problems initially encountered with off-the-shelf FF, and the minor fixes required to get rid of those problems; runs experiments showing the dramatic performance gains obtained this way, making this approach practical. Discusses open issues for planning technology in this domain.

# Reading

- *On-line Planning and Scheduling: An Application to Controlling Modular Printers* [Ruml *et al.* (2011)].

  Available at:

  `http://www.jair.org/media/3184/live-3184-5462-jair.pdf`

  Content: Comprehensive and detailed description of the application context, the configuration of planning and scheduling techniques used, and the added value obtained in doing so.

  For a shorter introduction of this application, refer to [Ruml *et al.* (2005)] available at:

  `http://www.cs.unh.edu/~ruml/papers/icaps-05-revised-1.pdf`

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