AI Planning

4. Applications

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

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Winter Term 2018/2019

Thanks to Prof. Jörg Hoffmann for slide sources

Agenda

1. Introduction
2. Simulated Penetration Testing
3. Natural Language Generation
4. Modular Printing System Control
5. Other Interesting Benchmarks
6. Conclusion

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:

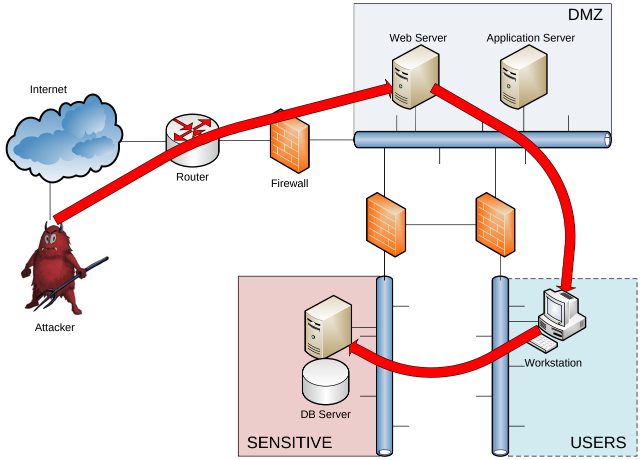
- Validate research ideas and techniques.
- Source of new research problems to consider.
- Source of useful benchmark examples to evaluate algorithms.

→ **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)

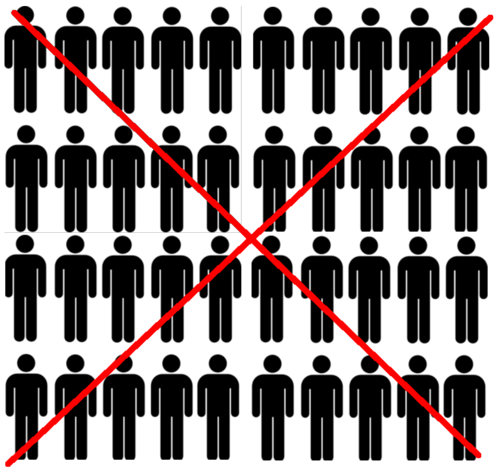
Pentesting

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.
  → 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

Security teams are typically small:



Motivation for Automation

Increase testing coverage:

Motivation for Automation

The security officer's "rat race":

Exploits

<< prev 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 next >>

Date	D	A	V	Description	Plat.	Author
1999-11-30	↓	-	✓	Qualcomm qpopper 3.0/3.0 b20 - Remote Buffer Overflow Vulnerability (2)	unix	Synnergy Networks
1999-11-30	↓	-	✓	Internet Explorer 4.1/5.0/4.0.1 Subframe Spoofing Vulnerability	windows	Georgi Guninski
1999-11-29	↓	-	✓	symantec mail-gear 1.0 - Directory Traversal Vulnerability	multiple	Ussr Labs
1999-11-26	↓	-	✓	Alt-N WorldClient Pro 2.0.0.0/2.0.1.0/Standard 2.0.0.0 - Long URL DoS Vulnerability	windows	Ussr Labs
1999-11-22	↓	-	✓	Microsoft Internet Explorer 5.0 for Windows 2000/95/98/NT 4 XML HTTP Redirect Vulnerability	windows	Georgi Guninksi
1999-11-19	↓	-	✓	Sun Solaris 7.0 rpc.ttdbserver Denial of Service Vulnerability	solaris	Elias Levy
1999-11-19	↓	-	✓	Microsoft SQL Server 7.0/7.0 SP1 NULL Data DoS Vulnerability	windows	Kevork Belian
1999-11-18	↓	-	✓	Dick Lin ZetaMail 2.1 Login DoS Vulnerability	windows	Ussr Labs
1999-11-17	↓	-	✓	Tektronix Phaser Network Printer 740/750/750DP/840/930 PhaserLink Webserver Vulnerability	hardware	Dennis W. Mattiso.
1999-11-16	↓	-	✓	Matt Wright FormHandler.cgi 2.0 Reply Attachment Vulnerability	unix	m4rcyS
1999-11-15	↓	-	✓	Admiral Systems EmailClub 1.0.0.5 - Buffer Overflow Vulnerability	windows	UNYUN
1999-11-15	↓	-	✓	Antelope Software W4-Server 2.6 a/Win32 Cgitest.exe Buffer Overflow	windows	UNYUN
1999-11-15	↓	-	✓	International TeleCommunications WebBBS 2.13 login & password Buffer Overflow	windows	UNYUN
1999-11-14	↓	-	✓	Microsoft Internet Explorer 5.0 Media Player ActiveX Error Message Vulnerability	windows	Georgi Guninski
1999-11-13	↓	-	✓	ETL Delegate 5.9.x / 6.0.x - Buffer Overflow Vulnerabilities	linux	scut

Motivation for Automation

$\Longrightarrow$ **Simulated Pentesting:**

- Make a model of the network and exploits.
- Run attack planning on the model to simulate attacks.
- Running the rat race $\approx$ update the model, go drink a coffee.

Motivation for Automation: Wrap-Up

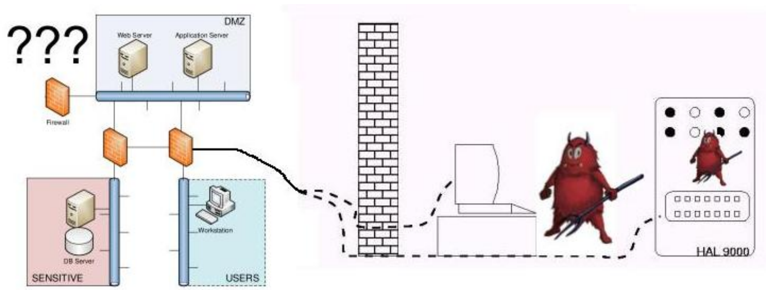
Simulated penetration testing serves to:

- 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, ...).

→ 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.

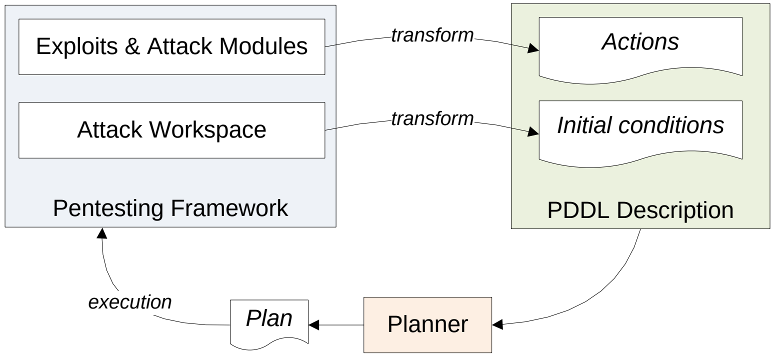
The Turing Test, Revisited

Ultimate vision: realistically simulate a human hacker!



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?

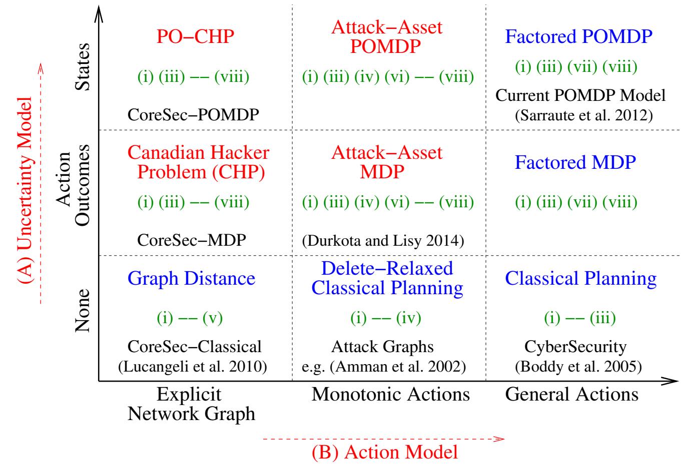
(A): Yes. (B): No.

→ Definitely not. Some examples of what is missing:

- The attack planner knows the network structure, the precise software installation, and where the sensitive data is!
- The attack planner does not use commonsense knowledge to guess passwords (birthdays, kids' names, . . .).
- The attack planner does not write phishing emails.

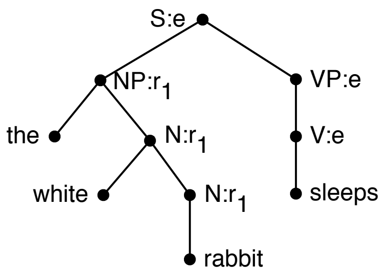
Research → FAI BSc/MSc/HiWi; Cooperation CISPA

Explore the trade-off: (between model accuracy and feasibility)



. . . and develop effective algorithms for these models.

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:

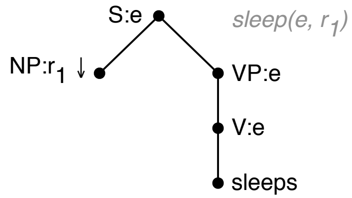
- Given semantic representation (formula) and grammar, compute sentence that expresses this semantics.
- Standard problem in natural language processing, many different approaches exist.

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

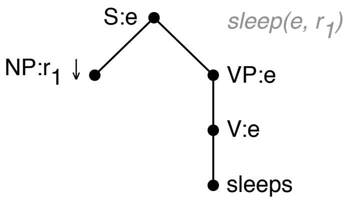
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1),\ rabbit(r_1),\ white(r_1),\ rabbit(r_2)\}$.



- "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.

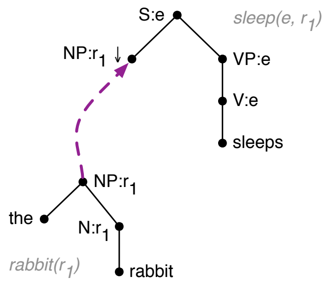
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1),\ rabbit(r_1),\ white(r_1),\ rabbit(r_2)\}$.



- Is this a complete sentence derivation? No, there exists an open node ("NP:$r_1 \downarrow$") that must be substituted.

NLG with TAG: Example, ctd.

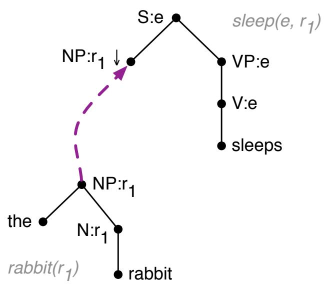
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1),\ rabbit(r_1),\ white(r_1),\ rabbit(r_2)\}$.



- 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.

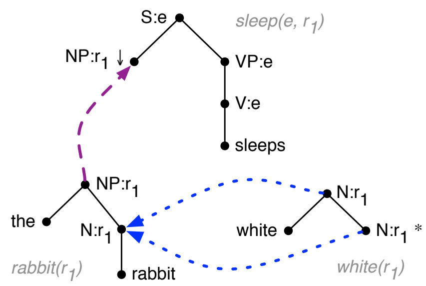
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1), rabbit(r_1), white(r_1), rabbit(r_2)\}$.



- Is this a complete sentence derivation? Yes (no open nodes).
- Does the sentence express the desired meaning? No. The intended subject r_1 is not uniquely identified, we must get rid of the ambiguity between r_1 and r_2.

NLG with TAG: Example, ctd.

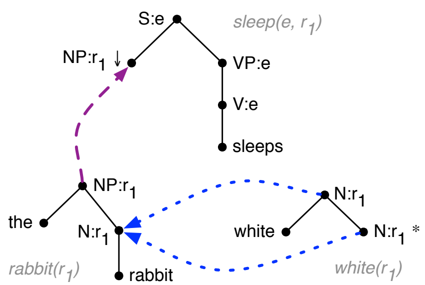
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1), rabbit(r_1), white(r_1), rabbit(r_2)\}$.



- 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.

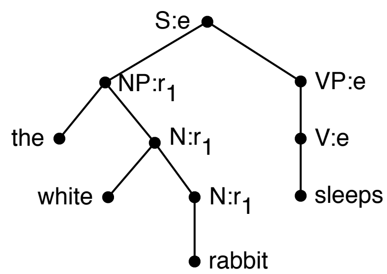
Task: Express ground atom $\{sleep(e, r_1)\}$.
Knowledge Base: $\{sleep(e, r_1), rabbit(r_1), white(r_1), rabbit(r_2)\}$.



- Is this a complete sentence derivation? Yes (no open nodes).
- Does the sentence express the desired meaning? Yes: According to the knowledge base, r_2 is not white, so r_1 is now uniquely identified.

NLG with TAG: Example, ctd.

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



- 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: $subst(S, u_0)$, $ref(u_0, e)$, $sleep(e, r_1)$, $rabbit(r_1)$, . . .

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**$(u_1, r_1)\rangle$.

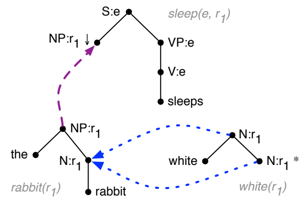
Questionnaire

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



→ The parameter u stands for the root of the verb-phrase tree, not for its subject. Further, $\neg subst(S, u)$ means that u is closed, not that it's open. Hence: (C) no, (D) yes.

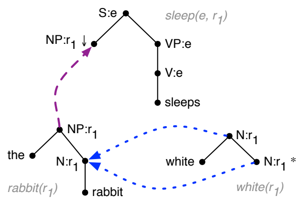
Questionnaire, ctd.

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



→ (A), (B), (D): No, the parameters u, u' stand for grammar tree nodes. (C): Yes, u_1 instantiates u' which refers to the noun phrase node in the tree corresponding to this action.

Research → FAI BSc/MSc/HiWi; Cooperation CoLi

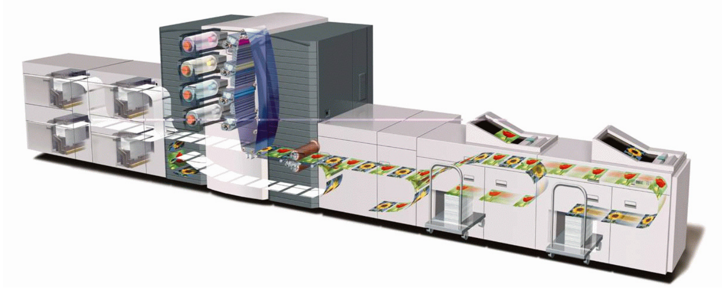
Status Quo: There are many search problems in Computational Linguistics – text/sentence generation, parsing, text-to-speech synthesis. Yet CoLi and AI Search have developed largely independently for decades.

→ Manifold opportunities for applying/adapting AI Search ideas to CoLi search problems.

Current Research: (collaboration with Profs. Demberg, Klakow, Koller)

- Surface Realization: *How* to express something, so that it sounds natural and is adequate for the audience and context?
- Linguistic Distance: As captured by the "best" set of transformation rules aligning word tuples across languages. Measuring the alignment cost for a given set of rules = optimal planning.
- Instruction giving in Minecraft: How to automatically generate instruction texts/videos? (Combines high-level discoure planning with low-level NLG.)

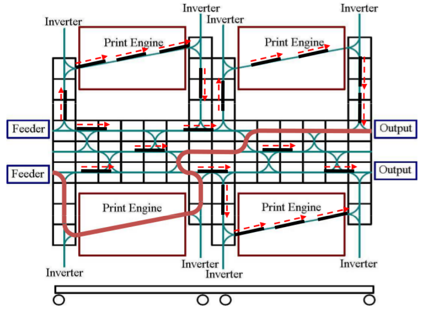
Large-Scale Printing Systems: Complex stuff already . . .



- 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.

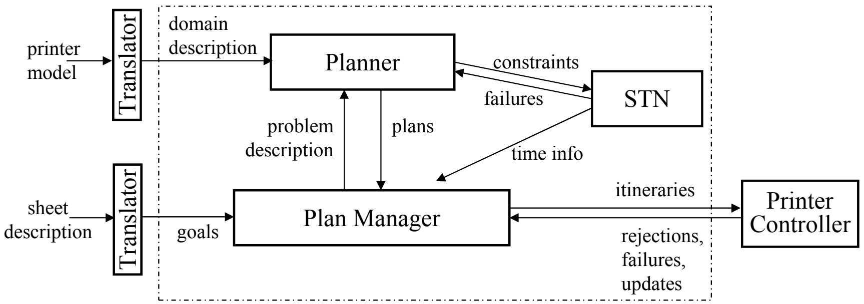
. . . and now we're making it MUCH worse!

MODULAR Large-Scale Printing Systems:



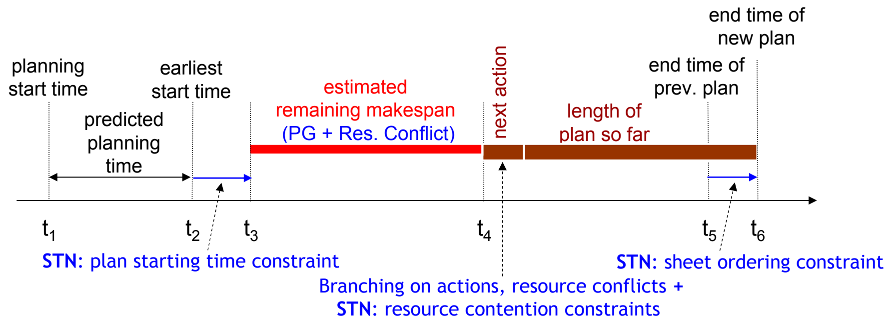
- Assemble and configure components as required by customer.
- No need to buy stuff you don't want, easy to adapt as needed.
- Control can no longer be pre-programmed/configured for a particular machine.
- Requires flexible software that can control anything we could build!

Planning To the Rescue!



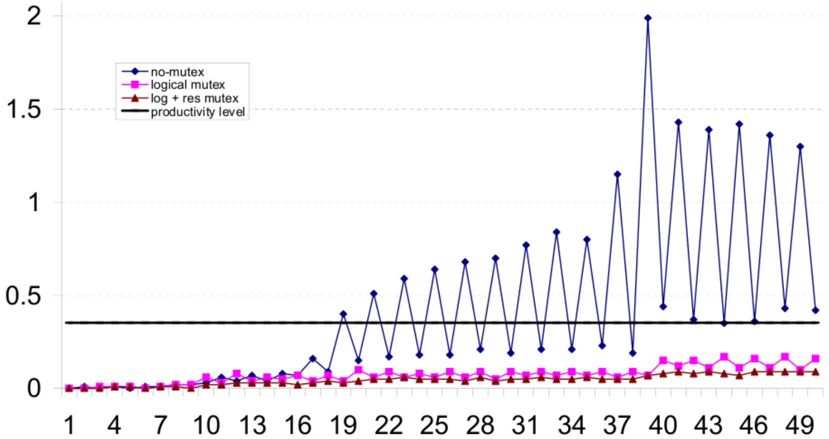
- "Planner" as opposed to "Plan Manager": Finding a solution for the task at any given point in time, vs. managing the updates to the task (new jobs arriving, job cancelled due to paper jam, . . .).
- "STN": Simple Temporal Network. A constraint-based representation of action durations and precedence 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.
  → h^2 is the key element making this work!

Research → FAI BSc/MSc/HiWi; Cooperation DFKI

Industrie 4.0!

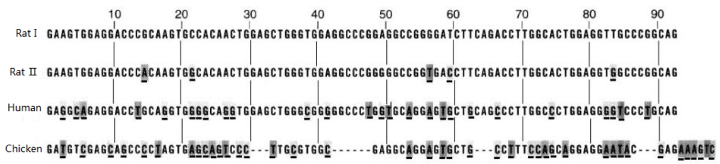
http://en.wikipedia.org/wiki/Industry_4.0

Very Similar Profile:

- From inflexible production of "always the same product" . . .
- . . . to flexible production of highly customizable products.
- Lots of control problems requiring the ability to deal with very general input.
- (Among many many other challenges . . .)

Genome Edit Distance

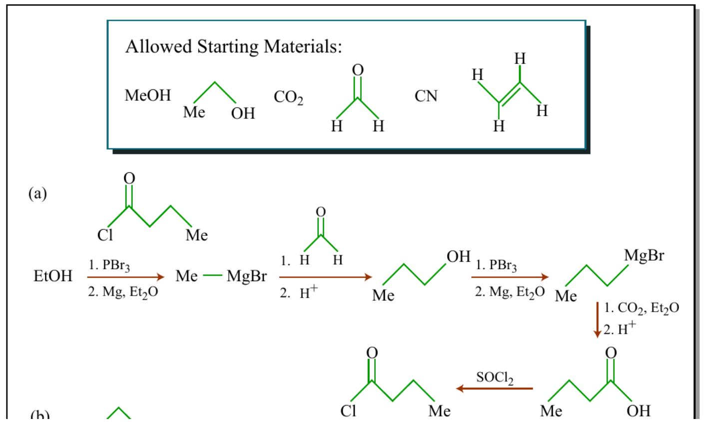
- Find a min-cost sequence of operations that transforms one genome into another.
- The purpose of this is to use this cost as a measure of the distance between the two genomes, which is used to construct hypotheses about the evolutionary relationship between the organisms.



Organic Synthesis

- MIT Chemistry Exam Problems

9. Provide synthesis for the following compounds. All of the carbons in the target molecules should be derived from the allowed starting materials. You may use any common reagents.



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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