Captain Jack:
New Variable Selection Heuristics in Local Search for SAT

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http://www.cs.ubc.ca/research/captain-jack

Key Contribution:

- Captain Jack is a *highly parametric* algorithm

  Incorporates elements from

  Sparrow

  [Balint, Fröhlich, SAT 2010]

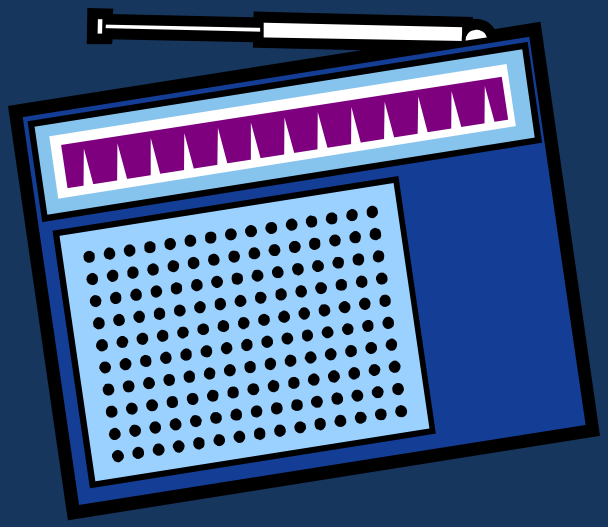
  & VE-Sampler

  [Tompkins, Hoos, SAT 2010]

good performance
"jack of all trades"

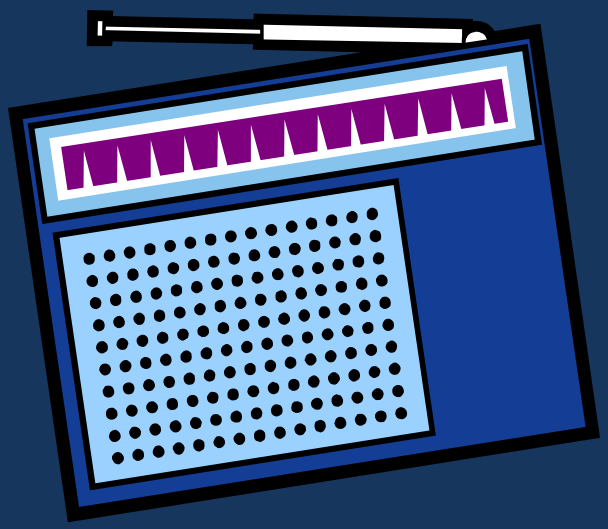
"interesting"
configuration
space

Algorithm Design Philosophy



Parameterless Algorithm

Algorithm Design Philosophy



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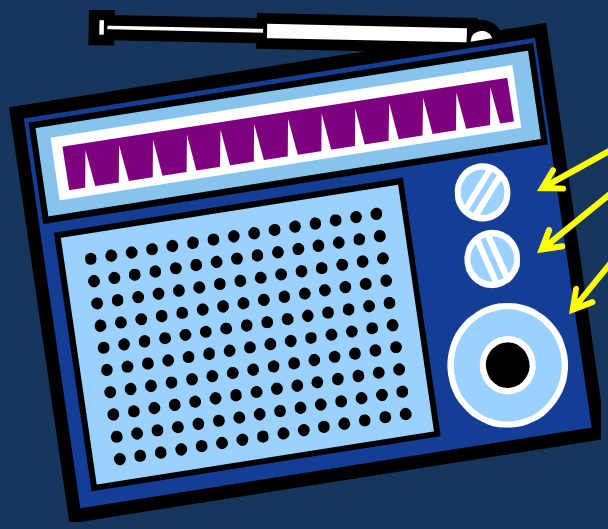
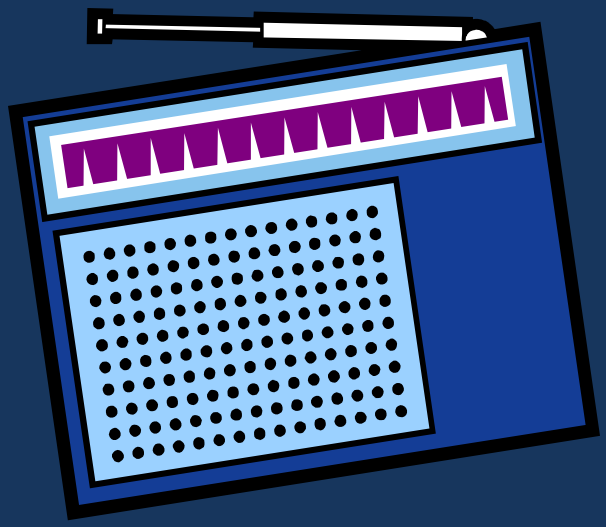


Algorithm Parameters

Algorithm Design Philosophy



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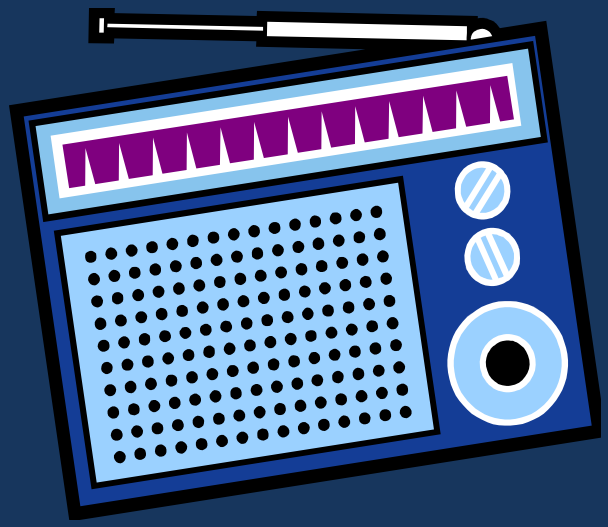
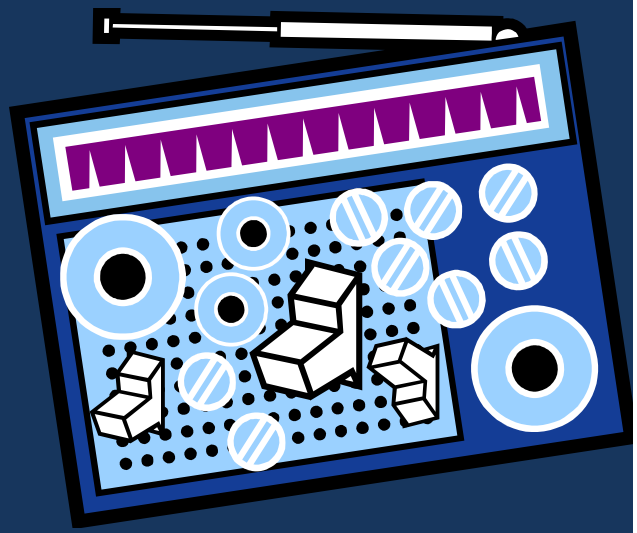




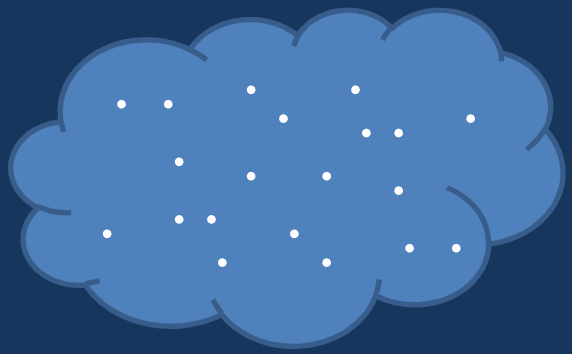
Highly Parametric Algorithm

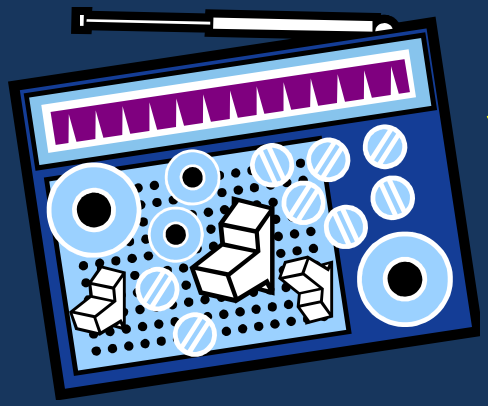
Automated Configuration

- We can use automated configurators to determine the optimal algorithm parameters for a target instance set
- We used ParamILS [Hutter *et al.*, 2007, 2009]
- Offload tedious human tasks to machines

Automated Configuration

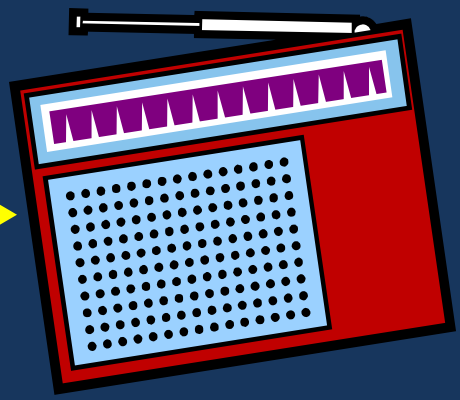
Training Instance Set





Highly Parametric Algorithm

Automated Configurator (here: ParamILS)

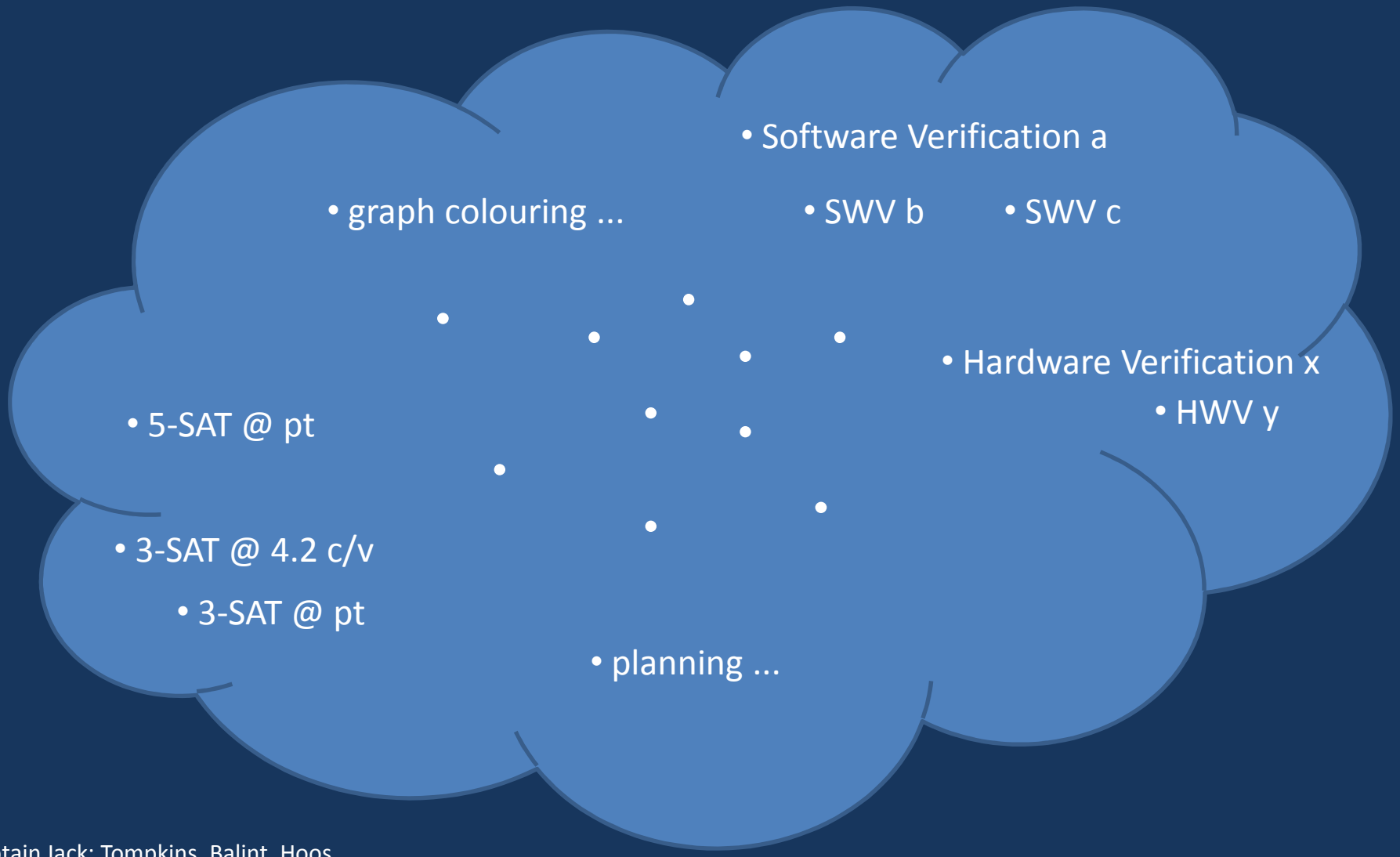


Tuned (configured) Algorithm

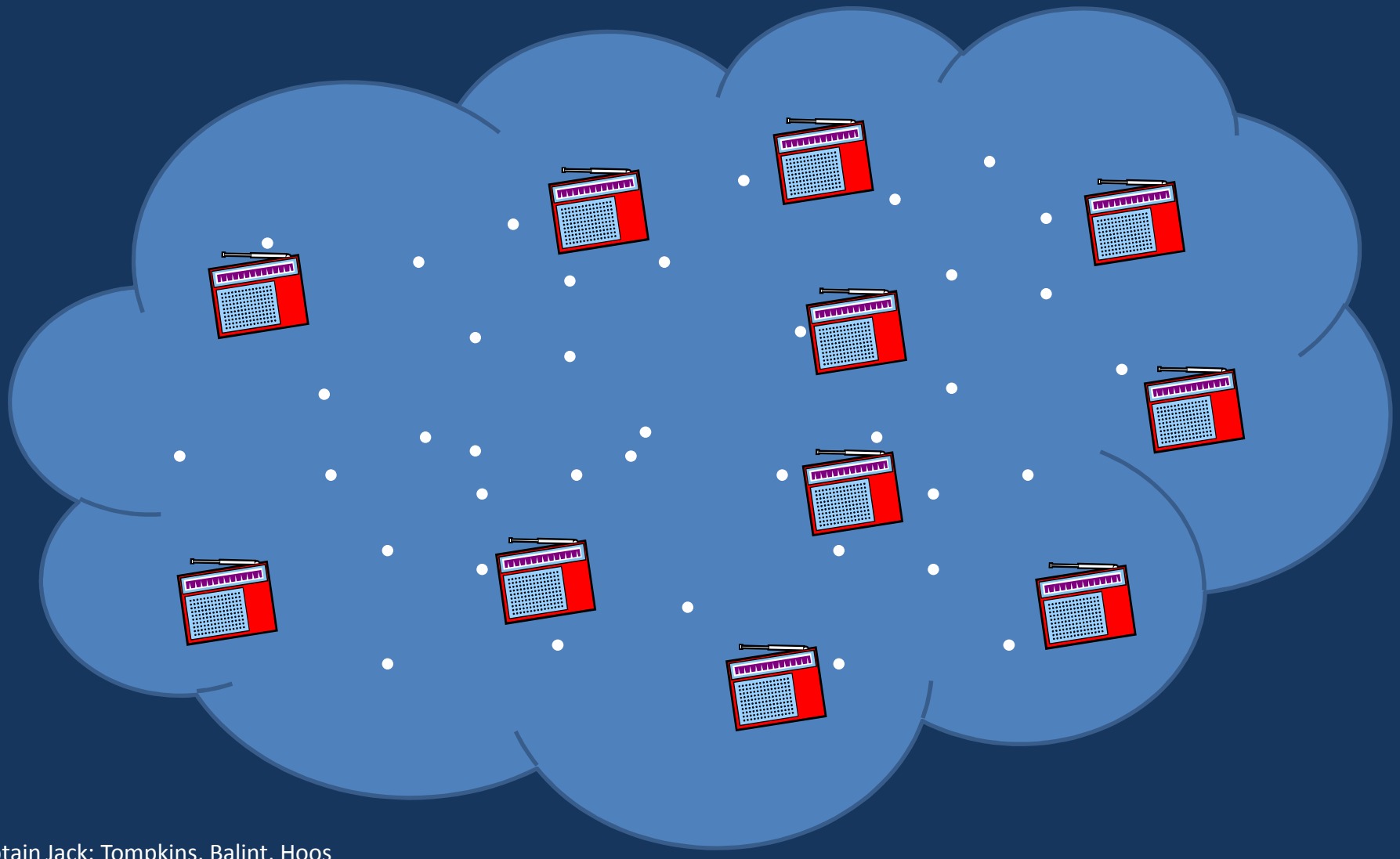
Instance "Space"

3-SAT @ pt

Instance "Space"



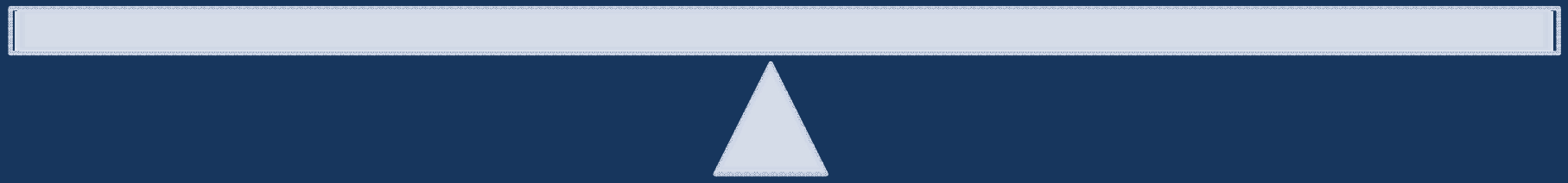
Algorithm "Space"



Captain Jack

good performance

"interesting" configuration space



Overview

- Motivation
- Captain Jack
  - Background
  - Design
  - New Contributions
- Results
- Future Work
- Conclusions

Stochastic Local Search (SLS) for SAT

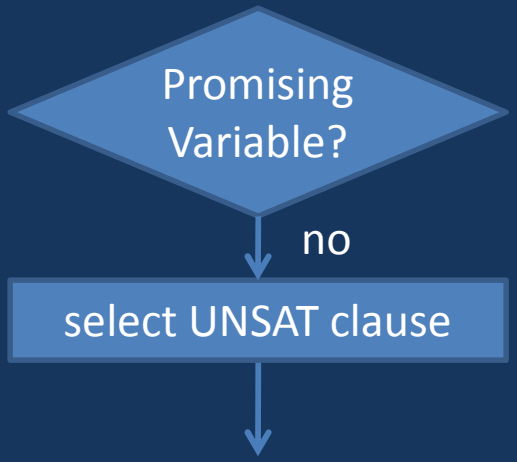
randomly initialize all variables
while (formula not satisfied)
    select a variable and "flip" it

$$(\neg x_1 \vee x_2 \vee \neg x_5)$$

Evaluate each variable (Variable Expression)

Variable Selection Mechanism (VSM)

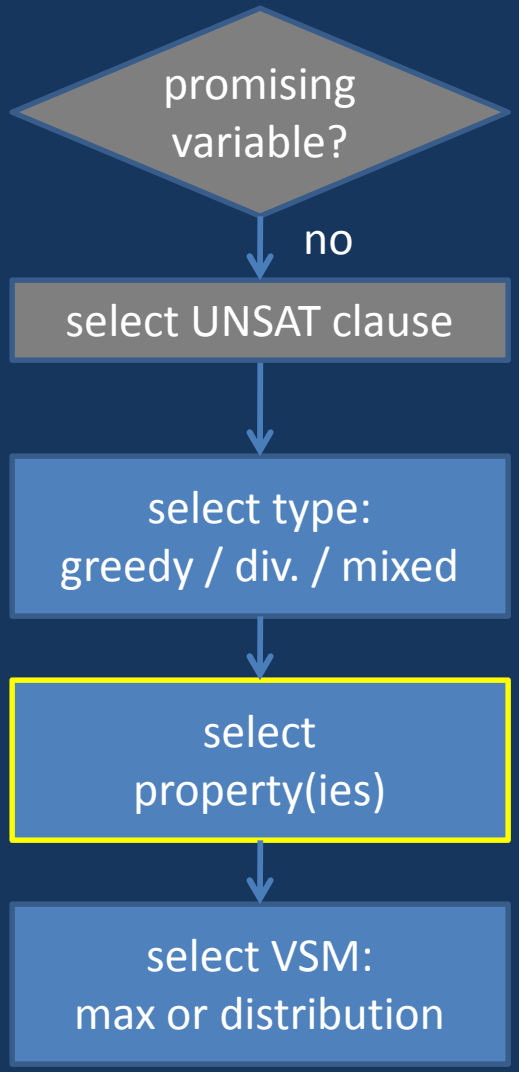
Captain Jack Controller



Captain Jack can use promising variables (if they exist)
[G^{2}WSAT: Li, Huang, 2005]

Select UNSAT clause uniformly at random
[Papadimitriou, 1991]
[WalkSAT: Selman, Kautz, Cohen, 1994]

Captain Jack Controller



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Variable Properties

- Greedy Properties

  make = # of clauses that become satisfied if we flip x

  break = ... unsatisfied ...

  score = (make – break) [GSAT: Selman, Levesque, Mitchell, 1992]

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  age = # of steps since x was flipped [TABU: Glover, 1986]
  flips = # of times x has been flipped [HSAT: Gent, Walsh, 1993]

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- Variable Expressions

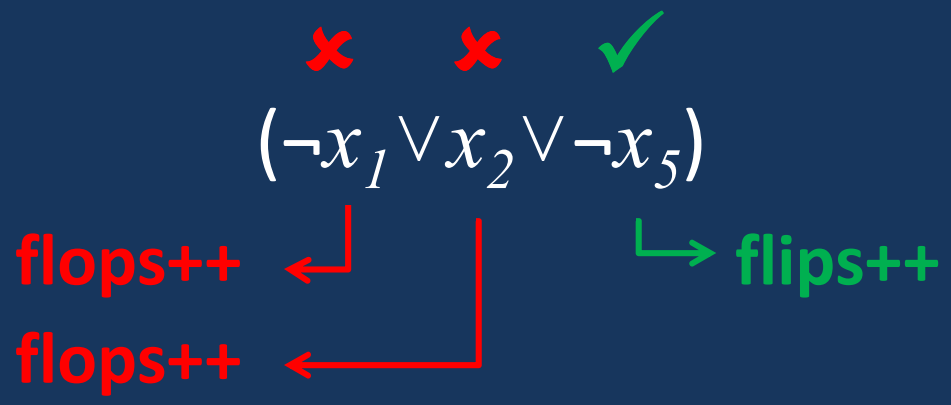
  sparrowAge $1+\left(\frac{age}{c_d}\right)^{c_e}$

Captain Jack Variable Properties

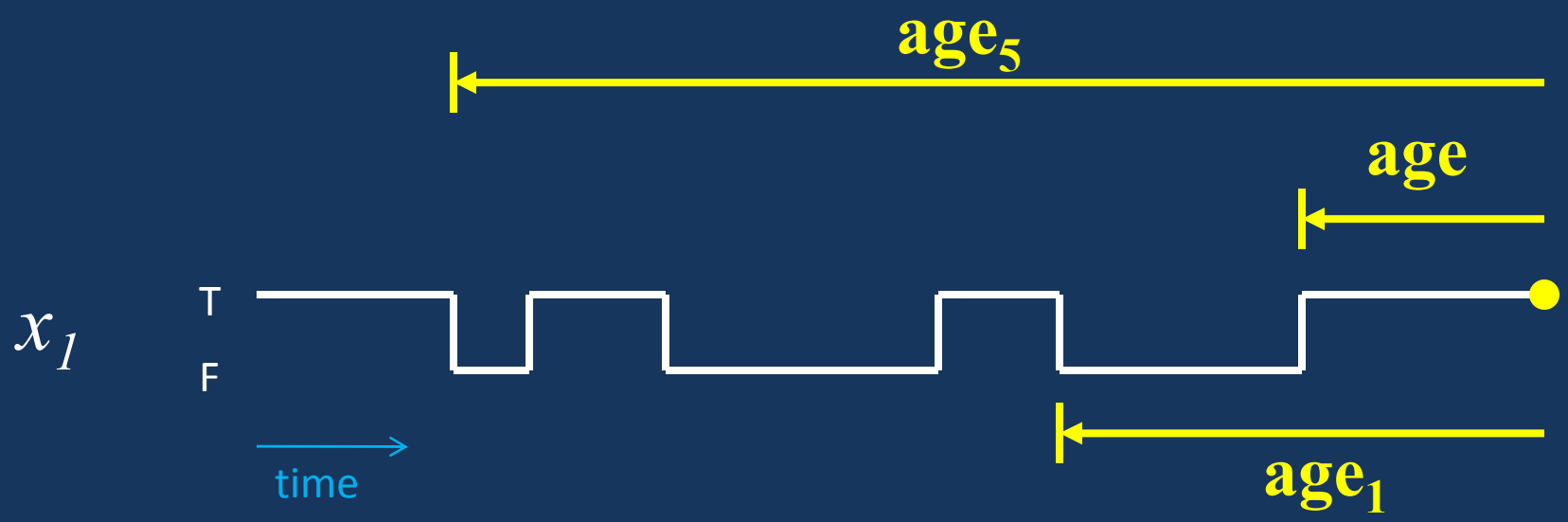
- Greedy
  - make
  - break
  - score
  - sparrowScore_2
  - score
  - scoreRatio
  - rel*
- Diversification
  - rand
  - flat
  - fair
  - last
  - age
  - age_1
  - age_5
  - ageRange
  - sparrowAge
  - tabu
  - flips
  - flops
  - normFlops
  - resetFlops
  - rel*

New Variable Properties

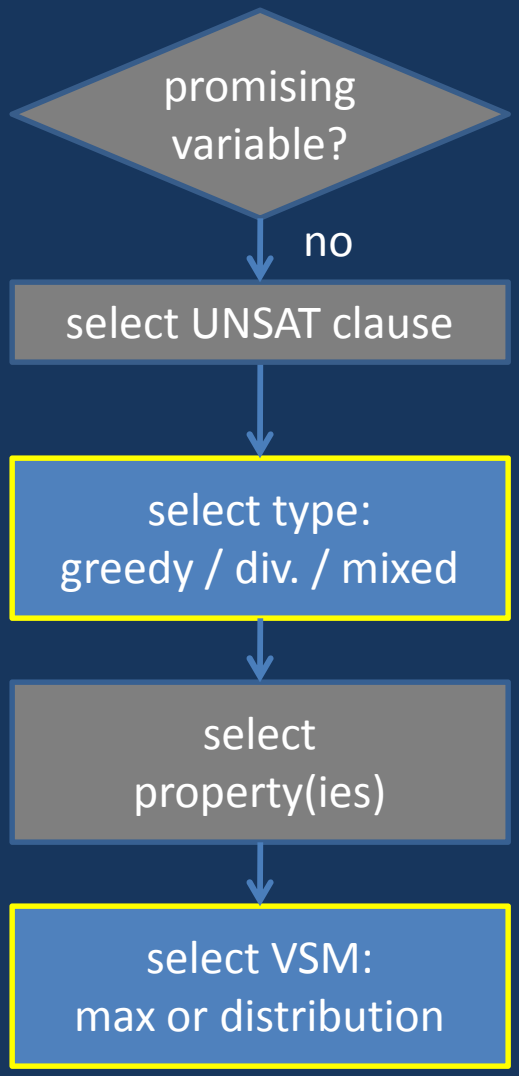
- scoreRatio: (make)/(make + break)
- flops:



age_k property



Captain Jack Controller



Mixed Variable Expressions

- VE-Sampler
  f(greedy) + f(diversification)
- Sparrow
  f(greedy) · f(diversification)
- both use a mixed VE
  - First introduced with VW2 [Prestwich, 2005]
- Captain Jack
  - 3 Options: greedy, diversification, mixed
  - greedy · diversification

Variable Selection Mechanism

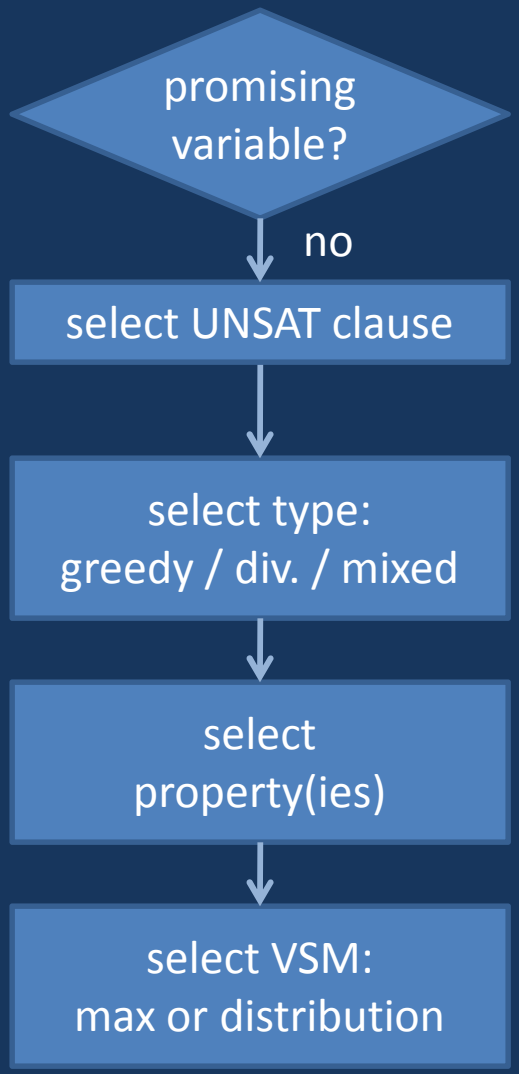
$(\neg x_1 \vee x_2 \vee \neg x_5)$

Variable Expression

x_1	5
x_2	4
x_5	1

- Maximum ("best")
  - select x_1
- Probability Distribution
  - select x_1 50%
  - select x_2 40%
  - select x_5 10%

Captain Jack Controller

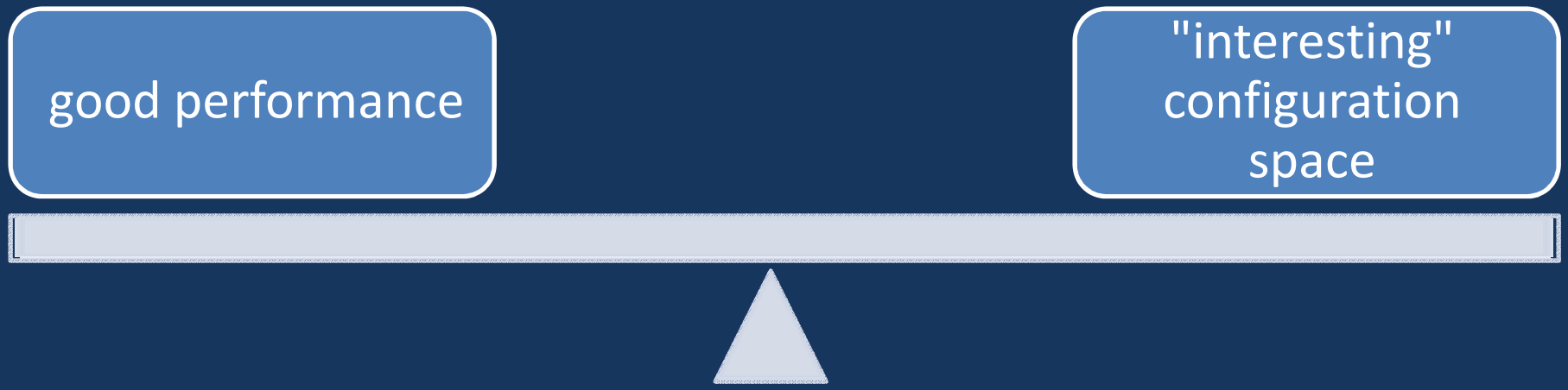


Each type of step assigned a weight (%)

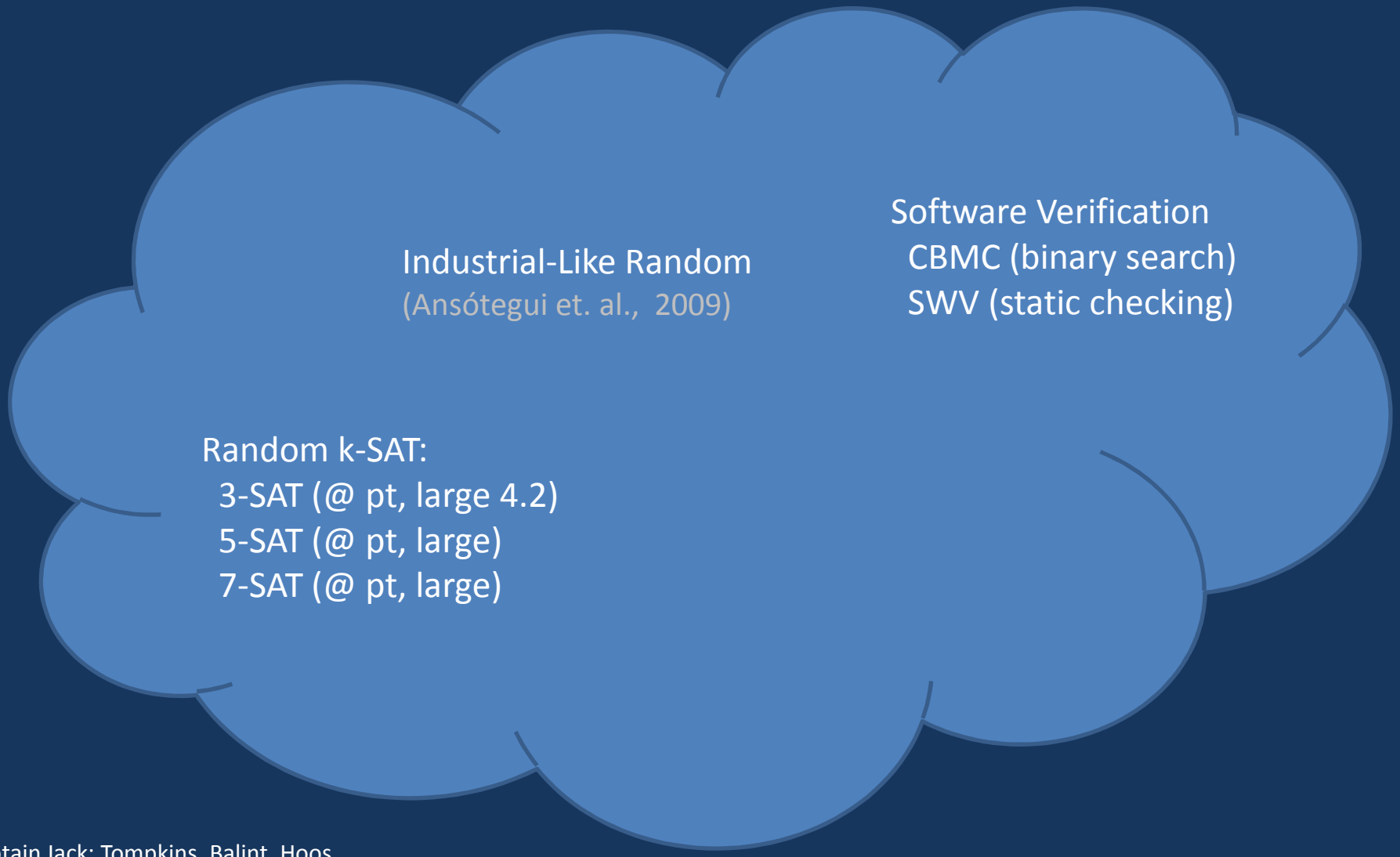
Each property is assigned a weight (%)
(both a greedy & div. property selected for mixed)

Prob. of selecting the VSM is based on the type

Captain Jack



Instance "Space"



Performance Results

	3-SAT		5-SAT		7-SAT				
	1k	10k	100	500	60	90	IL50k	CBMC	SWV
Captian Jack	2.06	**1.00**	1.72	3.66	1.83	4.43	**1.00**	4.38	1.59
Sparrow*	1.88	5.07	**1.00**	3.87	**1.00**	2.08	1.65	867	1.54
VE-Sampler*	2.46							**1.00**	**1.00**
SATenstein*	**1.00**	1.67	1.17	**1.00**	1.14	2.19	1.42	7.75	1.62
TNM	2.25	15.96	1.22	8.20	2.37	1.96	422	6,563	1.62
gNovelty+2	2.35	60.15	1.50	3.38	1.36	1.42	2,291		
AG2009++	2.28	54.81	1.17	7.35	1.90	**1.00**	8.27	40,837	1.48

time relative to fastest solver [PAR10]

Captain Jack: Tompkins, Balint, Hoos

Greedy Properties (%)

	3-SAT		5-SAT		7-SAT				
	1k	10k	100	500	60	90	IL50k	CBMC	SWV
make*		40	3				19	15	
break*		10	3		50	47	9	6	9
score*	10	10	3	20		3	71	27	12
sparrowScore$_2$	79	40	90	78	50	47			3
scoreRatio*	10			2				52	75

property weights as percentages, values ≤ 1 not shown

Diversification Properties

	3-SAT		5-SAT		7-SAT				
	1k	10k	100	500	60	90	IL50k	CBMC	SWV
random/flat/fair	15	11	2	46		52	2	6	2
last	15	5	4		10	13			
age*	59	75	87	51	84	18	47	46	47
flips*	4		2				48	42	45
flops*	8	10	5	3	3	18	3	7	4

property weights as percentages, values ≤ 1 not shown

Age-based Properties

	3-SAT		5-SAT		7-SAT				
	1k	10k	100	500	60	90	IL50k	CBMC	SWV
age	4	10	33		3	13			3
age$_1$		20	16				43		
age$_5$	15	40	4		20			42	44
ageRange	7			3					
sparrowAge	29				20	2	3		
tabu	4	5	33	44	41	3			

property weights as percentages, values ≤ 1 not shown

Cross-Testing

Configuration	3-SAT		5-SAT		7-SAT		IL50k	CBMC	SWV
	1k	10k	100	500	60	90			
CJ [3sat1k]	1	61.5	1.38	95.7	1.08	1.03	157	5 876	1.02
CJ [3sat10k]	2.65	1	1.41	545	1.99	3.99	167	1 890	1.02
CJ [5sat100]	2.56	135	1	93.2	1.18	**0.72**	170	7 108	1.03
CJ [5sat500]	24.3	200	1.35	1	1.00	**0.97**	1 271	10 014	1.00
CJ [7sat60]	99.1	200	**0.82**	539	1	2.33	786	9 989	1.02
CJ [7sat90]	105	200	1.82	12.1	1.44	1	1 929	3 088	**0.98**
CJ [IL50k]	16.6	200	4.50	567	2.20	15.8	1	1 106	**0.83**
CJ [CBMC]	19.9	200	6.71	483	2.97	7.70	1 236	1	1.02
CJ [SWV]	148	200	17.6	567	9.47	79.2	2.29	2.43	1

time relative to target configuration [PAR10]

Additional Observations

- No promising steps for CMBC & SWV
- Mixed Steps were preferred
- Variable Selection:
  - No clear winner between: Max/Probability Distribution
- No clear results on clause-length settings

Key Contributions

- CJ is a new *highly parametric* SLS algorithm
- Introduced several new variable properties
- Performs well on both random, industrial* and industrial-like
- Insights into configurations and properties used on different instances

Future Work

- age_k properties
- framework to introduce new properties
- "knock-out" algorithm properties
- adaptive strategies
- lead to specialized light-weight algorithms

- thanks...

Captain Jack: Tompkins, Balint, Hoos