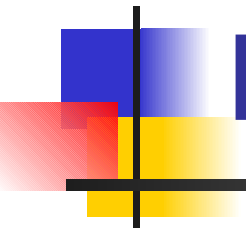
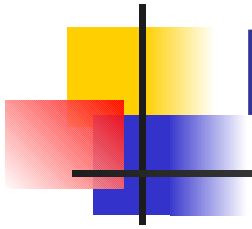


Heuristic POCL Planning

Håkan L. S. Younes

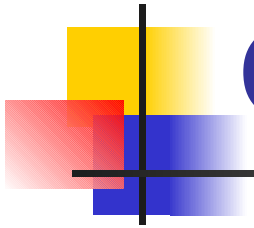
Carnegie Mellon University



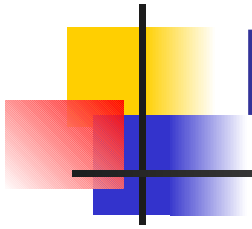
POCL Planning

- Search through plan-space
- Record only essential action orderings and variable bindings
  - Partial order
  - Lifted actions
- Causal links track reasons for having an action in a plan

Early to mid 1990's: Glory-Days of POCL Planning

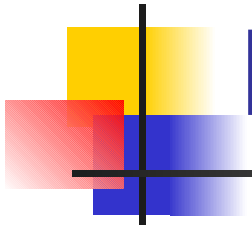


- Dominating planning paradigm in early 1990's
  - SNLP (McAllester & Rosenblitt 1991)
  - UCPOP (Penberthy & Weld 1992)
- Theoretically appealing, but remained inefficient despite significant research effort until mid 1990's



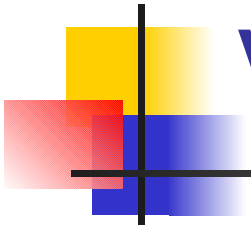
Paradigm Shift

- Planning graph analysis
  - Graphplan (Blum & Furst 1995)
- Planning as propositional satisfiability
  - SATPLAN (Kautz & Selman 1996)
- Heuristic search planning
  - HSP (Bonet & Geffner 1998)
  - FF (Hoffman & Nebel 2001)



Revival of POCL Planning

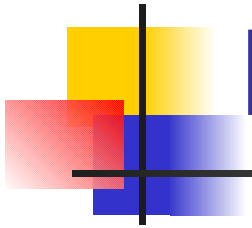
- RePOP (Nguyen & Kambhampati 2001)
  - Distance-based heuristic derived from serial planning graph
  - Disjunctive ordering constraints
  - Restricted to ground actions



VHPOP (2002)

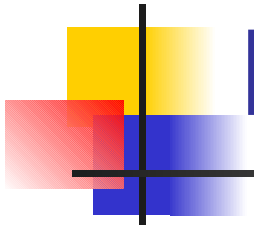
- Additive heuristic (HSP-r) for ranking partial plans
- Implements many novel flaw selection strategies
- Joint parameter domain constraints when planning with lifted actions (Younes & Simmons 2002)

Search Control in POCL Planning

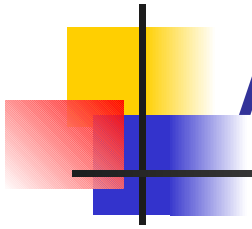


- Plan selection
- Flaw selection

Additive Heuristic for POCL Planning



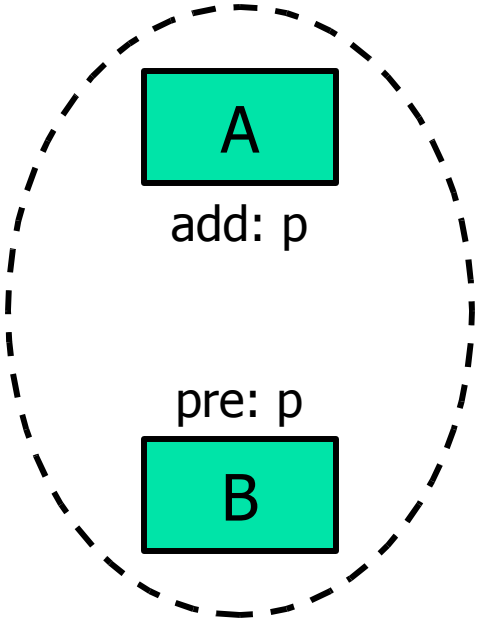
- Key assumption: Subgoal independence
- Heuristic value for open condition p:
  - Zero if p unifies with an initial condition
  - Minimum over heuristic values for ground actions having some effect unifying with p
- Heuristic value for partial plan:
  - Sum of heuristic values for open conditions



Accounting for Reuse

- Assign zero heuristic value to open condition that can be linked to some effect of an existing action

Accounting for Reuse (Example)



Additive heuristic: 1

With reuse: 0

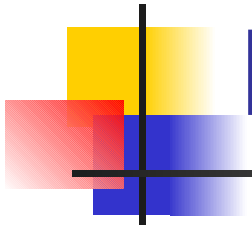
No Reuse vs. Reuse

	Problem	MW-Loc		MW-Loc-Conf		LCFR-Loc		LCFR-Loc-Conf	
		h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}
DriverLog	6	8.65	0.16	4.41	0.13	87.58	2.01	-	1.16
	7	3.66	0.34	0.63	0.17	21.15	1.28	1.57	0.22
	8	-	-	110.26	1.48	-	177.27	-	2.05
	9	-	0.33	-	0.28	-	-	-	-
	10	4.13	2.11	0.71	0.76	3.79	0.64	1.30	0.83
ZenoTravel	6	-	0.93	17.41	2.90	25.09	0.95	11.24	2.82
	7	-	-	-	37.81	-	-	-	33.10
	8	-	15.48	-	37.99	-	-	-	6.45
	9	-	86.21	-	11.53	-	33.37	26.33	9.49
	10	-	26.59	-	21.22	-	21.20	-	18.22

No Reuse vs. Reuse

Satellite

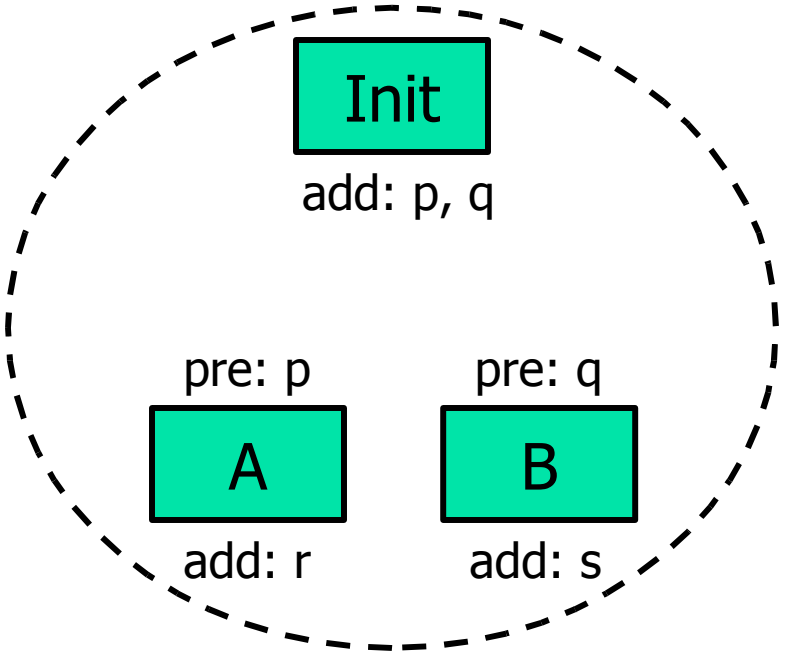
Problem	MW-Loc		MW-Loc-Conf		LCFR-Loc		LCFR-Loc-Conf	
	h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}
6	0.36	0.22	0.37	0.24	0.32	0.21	0.40	0.24
7	0.49	0.37	0.54	0.84	0.55	0.51	0.62	-
8	1.09	-	1.29	0.84	0.85	0.83	1.25	0.68
9	2.41	-	2.11	-	1.84	-	2.50	-
10	1.53	1.12	1.95	1.11	1.50	1.36	2.08	1.37



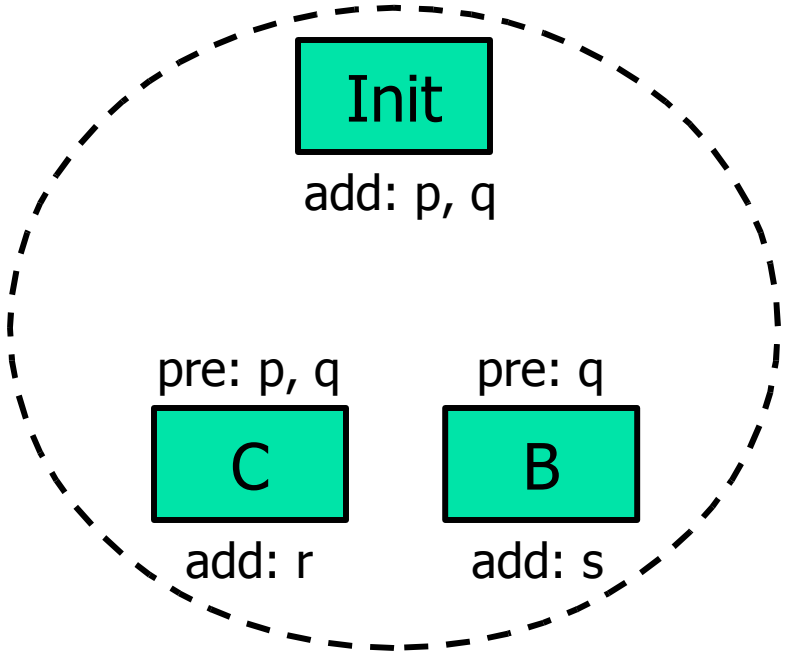
Estimated Effort

- Estimate of total number of open conditions that will have to be resolved
- Estimated effort for fully resolving an open condition p:
  - Like additive heuristic, but with value one if p unifies with an initial condition
- Use as tie-breaker

Estimated Effort (Example)



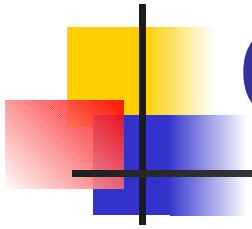
Additive heuristic: 0
Estimated effort: 2



Additive heuristic: 0
Estimated effort: 3

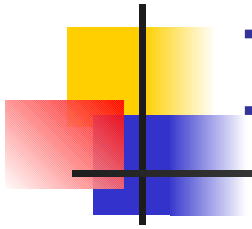
Estimated Effort as Tie-Breaker

Problem	h_{add}	with effort	h^r_{add}	with effort	RePOP
gripper-8	705	449	*	*	*
gripper-10	1359	795	*	*	*
gripper-12	2359	1294	*	*	*
gripper-20	12204	5558	*	*	*
rocket-ext-a	25810	20028	24507	20321	17768
rocket-ext-b	20034	19363	15919	6705	51540
logistics-a	301	287	621	317	191
logistics-b	488	404	694	326	436
logistics-c	422	346	629	227	2468
logistics-d	1398	1384	2525	682	*



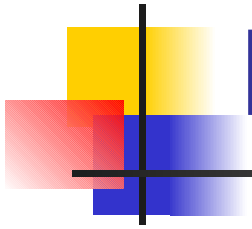
Old Flaw Selection Strategies

- UCPOP: Threats before open conditions
- DSep: Delay separable threats
- DUnf: Delay unforced threats
- LCFR: “Least cost flaw repair”
- ZLIFO: “Zero commitment LIFO”



Issues in Flaw Selection

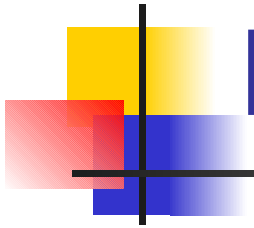
- Focus on subgoal achievement
  - Global vs. local flaw selection
- Sensitivity to precondition order



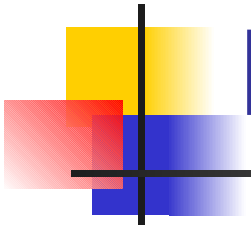
New Flaw Selection Strategies

- Early commitment through flaw selection
- Heuristic flaw selection
- Local flaw selection
- Conflict-driven flaw selection

Early Commitment through Flaw Selection

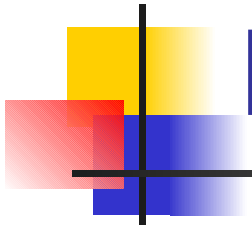


- Select static open conditions first
  - Static preconditions must be linked to the initial conditions
  - The initial conditions contain no variables
  - Therefore, linking static open conditions will bind action parameters to objects
- Can lead to fewer generated plans (Younes & Simmons 2002)



Heuristic Flaw Selection

- Use distance-based heuristic to rank open conditions
- Build plan from goals to start state
  - Most heuristic cost first
  - Most estimated effort first
- Build plan from start state to goals
  - Least cost/effort first



Local Flaw Selection

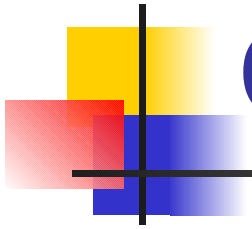
- Only select from open conditions of most recently added action with remaining open conditions
  - Helps maintain subgoal focus
- Can be combined with other strategies
  - LCFR-Loc
  - MW-Loc

Global vs. Local Flaw Selection

	Problem	UCPOP		LCFR		LCFR-Loc	
		σ/μ	n	σ/μ	n	σ/μ	n
DriverLog	6	0.20	20	0.01	20	0.01	20
	7	0.23	20	0.10	20	0.32	20
	8	0.28	17	-	0	0.00	1
	9	0.62	7	0.00	10	0.45	14
	10	0.33	16	-	0	0.07	20
ZenoTravel	6	0.27	20	0.03	7	0.22	20
	7	0.23	8	-	0	0.18	16
	8	0.29	11	-	0	0.15	19
	9	0.22	17	-	0	0.21	18
	10	0.26	18	-	0	0.22	17

Global vs. Local Flaw Selection

	Problem	MC		MC-Loc		MW		MW-Loc	
		σ/μ	n	σ/μ	n	σ/μ	n	σ/μ	n
DriverLog	6	0.18	20	0.23	20	0.02	20	0.02	20
	7	0.13	18	0.25	20	-	0	0.05	20
	8	-	0	-	0	-	0	-	0
	9	-	0	0.01	20	-	0	0.01	20
	10	-	0	0.08	20	-	0	0.08	20
ZenoTravel	6	-	0	0.00	20	-	0	0.00	20
	7	-	0	0.16	16	-	0	0.16	16
	8	-	0	0.18	20	-	0	0.18	20
	9	-	0	0.19	20	-	0	0.19	20
	10	-	0	0.15	19	-	0	0.15	19



Conflict-Driven Flaw Selection

- Select unsafe open conditions first
  - An open condition is unsafe if a link to it would be threatened
- Helps expose inconsistencies and conflicts early

Conflict-Driven Flaw Selection (Results)

	Problem	MW-Loc		MW-Loc-Conf		LCFR-Loc		LCFR-Loc-Conf	
		h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}	h_{add}	h^r_{add}
DriverLog	6	8.65	0.16	4.41	0.13	87.58	2.01	-	1.16
	7	3.66	0.34	0.63	0.17	21.15	1.28	1.57	0.22
	8	-	-	110.26	1.48	-	177.27	-	2.05
	9	-	0.33	-	0.28	-	-	-	-
	10	4.13	2.11	0.71	0.76	3.79	0.64	1.30	0.83
ZenoTravel	6	-	0.93	17.41	2.90	25.09	0.95	11.24	2.82
	7	-	-	-	37.81	-	-	-	33.10
	8	-	15.48	-	37.99	-	-	-	6.45
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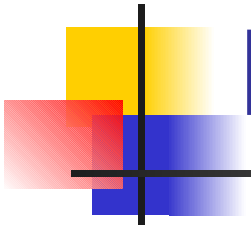
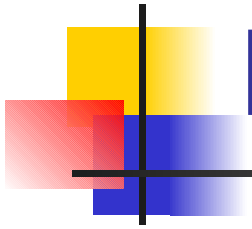


Planning with Durative Actions

- Replace ordering constraints with simple temporal network
- VHPOP currently uses same plan and flaw selection heuristics for temporal planning as for classical planning



Future of VHPOP

- Tailored heuristic functions for temporal planning
- Support for durations as functions of action parameters
- Use of landmarks

VHPOP: Versatile Heuristic Partial Order Planner

www.cs.cmu.edu/~lorens/vhpop.html