

Timetabling at Purdue University

March 24, 2010

Part I: Classical Course Timetabling

Coordinated decentralized timetabling for:

- a centrally timetabled **large lecture problem**
 - almost 900 classes timetabled into 55 rooms with up to 474 seats
- individually timetabled **departmental problems**
 - about 70 problems with 10 to 500 classes using departmental laboratory spaces and centrally managed classrooms allocated to departments based on expected class hours
- a centrally timetabled **computer laboratory problem**
 - about 200 classes timetabled into 31 rooms with 20 to 45 seats

GUI with generated timetable

Purdue Timetabling

https://oregano.smas.purdue.edu:18443/Timetabling/selectPrimaryRole.do

Purdue Timetabling

Timetable

Filter

Export PDF Refresh

Timetable

Legend

EE 129 (448)	7:30a	8:00a	8:30a	9:00a	9:30a	10:00a	10:30a	11:00a	11:30a	12:00p	12:30p	1:00p	1:30p	2:00p	2:30p	3:00p	3:30p	4:00p	4:30p	5:00p
Mon			MA 16200 Lec 1 0, 7, 0		PSY 12000 Lec 4 0, 0, 0		EDCI 27000 Lec 1 0, 0, 0		ECON 21000 Lec 1 0, 33, 0		PSY 12000 Lec 5 0, 0, 0		MA 16100 Lec 2 0, 0, 0		CSR 34200 Lec 1 0, 23, 0		MA 16200 Lec 2 0, 0, 0		MA 26100 Lec 1 0, 0, 4	
Tue		SOC 22000 Lec 1 40, 0, 0		ECON 25100 Lec 3 0, 0, 0		ENGR 10000 Lec 1 0, 0, 0			ECON 21000 Lec 1 0, 33, 0		AGEC 33100 Lec 1 0, 0, 0		ECON 25100 Lec 1 0, 1, 0			SOC 10000 Lec 4 0, 0, 0		PSY 12000 Lec 2 8, 4, 0		
Wed			MA 16200 Lec 1 0, 7, 0		PSY 12000 Lec 4 0, 0, 0		ENGR 10000 Lec 3 0, 0, 0		ECON 21000 Lec 1 0, 33, 0		PSY 12000 Lec 5 0, 0, 0		MA 16100 Lec 2 0, 0, 0		CSR 34200 Lec 1 0, 23, 0		MA 16200 Lec 2 0, 0, 0		MA 26100 Lec 1 0, 0, 4	
Thu		SOC 22000 Lec 1 40, 0, 0		ECON 25100 Lec 3 0, 0, 0		ENGR 10000 Lec 2 0, 0, 0			AGEC 33100 Lec 1 0, 18, 1		PSY 12000 Lec 5 0, 0, 0		ECON 25100 Lec 1 0, 0, 0			SOC 10000 Lec 4 0, 0, 0		PSY 12000 Lec 2 8, 4, 0		
Fri			MA 16200 Lec 1 0, 7, 0		PSY 12000 Lec 4 0, 0, 0		ENGR 10000 Lec 3 0, 0, 0		CNIT 13600 Lec 1 0, 18, 1		PSY 12000 Lec 5 0, 0, 0		MA 16100 Lec 2 0, 0, 0			MA 16200 Lec 2 0, 0, 0		MA 26100 Lec 1 0, 0, 4		

EE 170 (172)	7:30a	8:00a	8:30a	9:00a	9:30a	10:00a	10:30a	11:00a	11:30a	12:00p	12:30p	1:00p	1:30p	2:00p	2:30p	3:00p	3:30p	4:00p	4:30p	5:00p
Mon	ECE 20100 Lec 3 0, 0, 4		CE 29700 Lec 1 0, 0, 0				AAE 20300 Lec 1 0, 0, 1		CE 20300 Lec 1 0, 0, 1		ENTM 41800 Lec 1 32, 27, 8		CE 34000 Lec 1 0, 0, 0		AAE 35200 Lec 1 10, 4, 2		AAE 30100 Lec 1 0, 4, 9		ECE 27000 Lec 1 0, 0, 0	
Tue		PHPR 47800 Lec 1 0, 0, 4		BCM 10000 Lec 1 4, 0, 0			PSY 23500 Lec 1 0, 0, 0		SOC 32400 Lec 1 0, 0, 0				PHAD 46400 Lec 1 0, 0, 0						CSR 20900 Lec 1 0, 0, 11	
Wed	ECE 20100 Lec 3 0, 0, 4		CE 29700 Lec 1 0, 0, 0		CS 15900 Lec 2 1, 0, 6		AAE 20300 Lec 1 0, 0, 1		CE 20300 Lec 1 0, 0, 1		CS 15900 Lec 2 0, 0, 2		CE 34000 Lec 1 0, 0, 0		AAE 35200 Lec 1 10, 4, 2		AAE 30100 Lec 1 0, 4, 9		ECE 27000 Lec 1 0, 0, 0	
Thu		PHPR 47800 Lec 1 0, 0, 4		BCM 10000 Lec 1 4, 0, 0			PSY 23500 Lec 1 0, 0, 0		SOC 32400 Lec 1 0, 0, 0				PHAD 46400 Lec 1 0, 0, 0			ECE 69400 Lec 1 0, 0, 0			CSR 20900 Lec 1 0, 0, 11	
Fri	ECE 20100 Lec 3 0, 0, 4		CE 29700 Lec 1 0, 0, 0		CS 15900 Lec 2 1, 0, 6		AAE 20300 Lec 1 0, 0, 1		CE 20300 Lec 1 0, 0, 1		CS 15900 Lec 2 0, 0, 2		CE 34000 Lec 1 0, 0, 0		AAE 35200 Lec 1 10, 4, 2		AAE 30100 Lec 1 0, 4, 9		ECE 27000 Lec 1 0, 0, 0	

MSEE B012 (96)	7:30a	8:00a	8:30a	9:00a	9:30a	10:00a	10:30a	11:00a	11:30a	12:00p	12:30p	1:00p	1:30p	2:00p	2:30p	3:00p	3:30p	4:00p	4:30p	5:00p
Mon	SLHS 30400 Lec 1 24, 0, 0		MSE 23500 Lec 1 0, 0, 0		CE 47300 Lec 1 0, 1, 4			ENGL 27600 Lab 1 0, 0, 0			POL 30000 Lec 1 0, 0, 4		EAS 10900 Lec 1 0, 0, 0			NUR 30200 Lec 1 0, 0, 0			AAE 43900 Lec 1 0, 0, 0	
Tue					HIST 30400 Lec 1 0, 0, 0			EAS 31200 Lec 1 0, 0, 0			HSCI 31200 Lec 1 0, 0, 4		HSCI 58000 Lec 1 0, 0, 0			ECE 30200 Lec 2 0, 0, 0			CSR 41500 Lec 1 0, 0, 3	
Wed	SLHS 30400 Lec 1 24, 0, 0				CE 47300 Lec 1 0, 1, 4			ENGL 27600 Lec 1 0, 0, 0			POL 30000 Lec 1 0, 0, 4		EAS 10900 Lec 1 0, 0, 0			NUR 30200 Lec 1 0, 0, 0			AAE 43900 Lec 1 0, 0, 0	
Thu					HIST 30400 Lec 1 0, 0, 0						HSCI 31200 Lec 1 0, 0, 4		HSCI 58000 Lec 1 0, 0, 0			ECE 30200 Lec 2 0, 0, 0			CSR 41500 Lec 1 0, 0, 3	
Fri	SLHS 30400 Lec 1 24, 0, 0		MSE 23500 Lec 1a 0, 0, 0		CE 47300 Lec 1 0, 1, 4			ECE 36400 LabP1 0, 0, 0											AAE 43900 Lec 1 0, 0, 0	

Current User: [Admin](#) [Admin](#) [Admin](#)

Name: [Mick](#) [Tomás](#)

Dept: [SMAS](#)

Role: [Administrator](#)

Session: [Fall 2009 \(PWL\)](#)

Status: [Timetabling](#)

Database: [smasdb@smasdev](#)

Version: [3.1.165 \(Purdue\)](#)

Logged: [12/11/09 07:50 AM](#)

Problem	Classes	Meetings per class	Hours per class	Classes per subpart	Students	Classes per students	Timetabled classes per student	Rooms	Room capacity (min-max)	Frequency (in %) (used slots)	Utilization (in %)	Distribution constraints per class
pu-spr07-llr	803	2.09	2.40	1.25	27881	3.15	0.00	55	40-474	67.77	62.54	0.69
pu-fal07-llr	891	2.07	2.32	1.26	30855	3.23	0.00	55	40-474	74.63	70.40	0.71
pu-spr07-ms	440	2.32	2.43	3.52	11992	1.11	3.13	25	24-51	84.43	76.18	2.74
pu-fal07-ms	525	2.35	2.40	4.45	14331	1.10	3.18	33	24-61	78.30	67.88	2.18
pu-spr07-cs	93	1.63	2.14	1.82	725	2.03	3.19	13	17-61	36.18	30.42	2.83
pu-fal07-cs	174	1.31	1.92	2.72	2002	1.57	4.00	13	22-61	52.19	44.93	2.49
pu-spr07-cfs	214	1.44	2.91	2.21	1610	1.94	2.94	29	10-71	41.52	26.70	1.79
pu-fal07-cfs	201	1.38	2.90	2.14	1936	1.75	3.17	28	10-71	39.73	23.14	3.28
pu-spr07-vpa	249	1.71	3.24	1.64	1836	2.17	2.47	47	10-45	34.34	28.80	2.06
pu-fal07-vpa	290	1.59	2.92	1.72	1747	2.22	2.42	41	10-45	40.39	32.81	1.26
pu-spr07-lab	443	1.25	1.97	4.82	8421	1.14	4.20	36	20-45	52.57	43.27	2.05
pu-fal07-lab	200	1.20	1.81	3.70	4835	1.08	4.49	31	20-45	27.19	23.21	3.29
pu-spr07-c8	2418	1.81	2.45	1.95	29514	4.16	0.00	213	10-474	55.27	56.35	1.76
pu-fal07-c8	2457	1.85	2.40	1.90	32399	4.10	0.00	208	10-474	56.83	61.29	1.74

Basic set of constraints

		Hard constraint	Soft constraint
Times for class	Time pattern	x	
	Individual times	x	x
Rooms for class	Individual buildings/rooms	x	x
	Individual room equipment	x	x
Resource constraints	Room	x	
	Instructor	x	
Students	Conflicts between two classes		x
Distribution constraints between classes	Time between classes	x	x
	Time precedences between classes	x	x
	Classes placed in similar times	x	x
	Same or different meeting days/times/rooms for classes	x	x

Model of course structure

Instructional Offering	Introduction to Actuarial Science		MATH 170		STAT 170	
Configuration	Traditional			Computer-Assisted		
Subpart	Lecture			Lecture		
<i>Parent</i>	Recitation			Recitation		
<i>Child</i>				Laboratory		
Class	Lec1			Lec3		
<i>Parent</i>	Rec1 Rec2			Rec5 Rec6		
<i>Child</i>				Lab1 Lab2		
	Lec2			Lec4		
	Rec3 Rec4			Rec7 Rec8		
				Lab3 Lab4		

Course structure with classes as displayed in user interface

	Mins Per		Limit	Manager	Date Pattern	Time Pattern	Preferences			Instructor
	Demand	Week					Time	Room	Distribution	
M E 263		98	96							
M E 263H										
Lecture		150	96	LLR	Full Term	3 x 50 2 x 75		WTHR Computer		
Recitation		100	96	M E	Full Term	2 x 50		ME 120 ME 236 Classroom		
Laboratory		50	84-120	LAB	Even Wks	1 x 50		Windows XP		
Lec 1		150	96	LLR	Full Term	3 x 50 2 x 75		WTHR Computer		J. Smith C. Bing
Rec 1		100	48	M E	Full Term	2 x 50		ME 120 ME 236 Classroom	Back-To-Back	J. Novak
Lab 1		50	14-20	LAB	Even Wks	1 x 50		Windows XP		
Lab 2		50	14-20	LAB	Even Wks	1 x 50		Windows XP		
Lab 3		50	14-20	LAB	Even Wks	1 x 50		Windows XP		
Rec 2		100	48	M E	Full Term	2 x 50		ME 120 ME 236 Classroom	Back-To-Back	J. Novak
Lab 4		50	14-20	LAB	Odd Wks	1 x 50		Windows XP		
Lab 5		50	14-20	LAB	Odd Wks	1 x 50		Windows XP		
Lab 6		50	14-20	LAB	Odd Wks	1 x 50		Mac Os X		

Weighted constraint satisfaction problem

- $P = (V, \mathcal{D}, C, w_c, w_\theta)$
- set of variables V
- set of finite domains \mathcal{D}
 - each $v \in V$ takes a value from D_v such that $D_v \in \mathcal{D}$
- set of hard and soft constraints $C = C_h \cup C_s$
 - constraint weight w_c as a function associating each soft constraint $c \in C_s$ with its weight $w_c(c)$
 - assignment weight as a function w_θ associating the value d of each variable v with its weight $w_\theta(v/d)$
- An assignment ω for a weighted CSP $(V, \mathcal{D}, C, w_c, w_\theta)$ is a set of pairs v/d such that $v \in V, d \in D_v, D_v \in \mathcal{D}$ and each v appears at most once in ω .
- assignment ω complete if each $v \in V$ appears in ω , otherwise ω is called a partial assignment

Solution of weighted CSP

- Consider a constraint $c \in C$ defined on variables $X \subseteq V$ and denote $n_c = \|X\|$ and $scope(c) = X$.
- Assignment ω **satisfies** the constraint c iff x_i/d_i exists in ω for all variables $x_i \in scope(c)$ and $(d_1, \dots, d_{n_c}) \in c$ holds (written $\omega \models c$).
- An assignment ω is **consistent** if it satisfies all of the hard constraints $c \in C_h$ whose scopes have no unassigned variables.
- A complete assignment ω which satisfies all hard constraints is called a **solution** (alternatively a solution is a complete consistent assignment).

Initial problem

$$F_s \omega = \sum_{c \in C_s \wedge \omega \models \neg c} w_c(c) + \sum_{v/d \in \omega} w_\theta(v/d)$$
$$F_{\text{wcsp}} \omega = (\|\omega\|, F_s \omega)$$

$$F_{\text{wcsp}} \omega \leq_{\text{wcsp}} F_{\text{wcsp}} \eta \equiv ((\|\omega\| > \|\eta\|) \vee ((\|\omega\| = \|\eta\|) \wedge (F_s \omega \leq F_s \eta)))$$

An **optimal solution of the initial problem** is a solution σ with the minimal $F_{\text{wcsp}} \sigma$.

Consider a consistent assignment ω with $F_{\text{wcsp}} \omega = (\|\omega\|, F_s \omega)$ and a new assignment v/d such that v is not present in ω . Such an assignment may increase the violation of soft constraints by the value

$$\Delta F_s(\omega, v/d) = w_\theta(v/d) + \sum_{c \in C_s \wedge v \in \text{scope}(c) \wedge \omega \not\models \neg c \wedge (\omega \cup \{v/d\}) \models \neg c} w_c(c)$$

Domain variable

- Each class is specified by a domain variable representing the desired values for meeting times (weeks and patterns of days the class should meet during the term, start times and duration of all meetings) and rooms.
- Domain variables will be denoted $v = (v_w, v_p, v_s, v_d, v_r)$ and their particular values $d = (d_w, d_p, d_s, d_d, d_r)$.
- Example:
 - Value $d = (11110000, MW, 7:30 \text{ am}, 50, WTHR 200)$
 - Domain variable $v = (v_w, v_p, v_s, v_d, v_r)$ with
$$(v_w, v_p, v_s, v_d) \in \{(11111111, MWF, 7:30 \text{ am}, 50), (11111111, MWF, 8:30 \text{ am}, 50), (11111111, MWF, 9:30 \text{ am}, 50), (11111111, TTh, 7:30 \text{ am}, 75), (11111111, TTh, 9:00 \text{ am}, 75)\}$$
and $v_r \in \{WTHR 200, CL50 224, EE 129, LILY 1105\}$

Hard constraints

- No constraint propagation
- Consistency of the constraint detected when the last variable is assigned
- Weak for non-binary constraints
- However, non-binary constraints can be translated to simpler constraints to check their consistency
- Example: resource constraint
 - a set of binary constraints prohibiting the placement of each pair of classes into overlapping time periods
 - implementation: array of assigned classes over time

- Soft unary constraints

$$w_{\theta}(v/d) = w_{\text{time}} w_{\theta}((v_w, v_p, v_s, v_d)/(d_w, d_p, d_s, d_d)) + w_{\text{room}} w_{\theta}(v_r/d_r)$$

- Student conflicts: soft constraint c between each two classes v_1 and v_2 with the weight $w_c(c) = s$ which is satisfied when the classes v_1 and v_2 do not overlap
- Soft distribution constraints with a weight $w_c(c)$