Linear Programming Tools for Scheduling Trainees in Healthcare

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Presentation Outline

- Background
- Motivation
- Model Formulation
- Model Implementation
- Conclusions and Future Work

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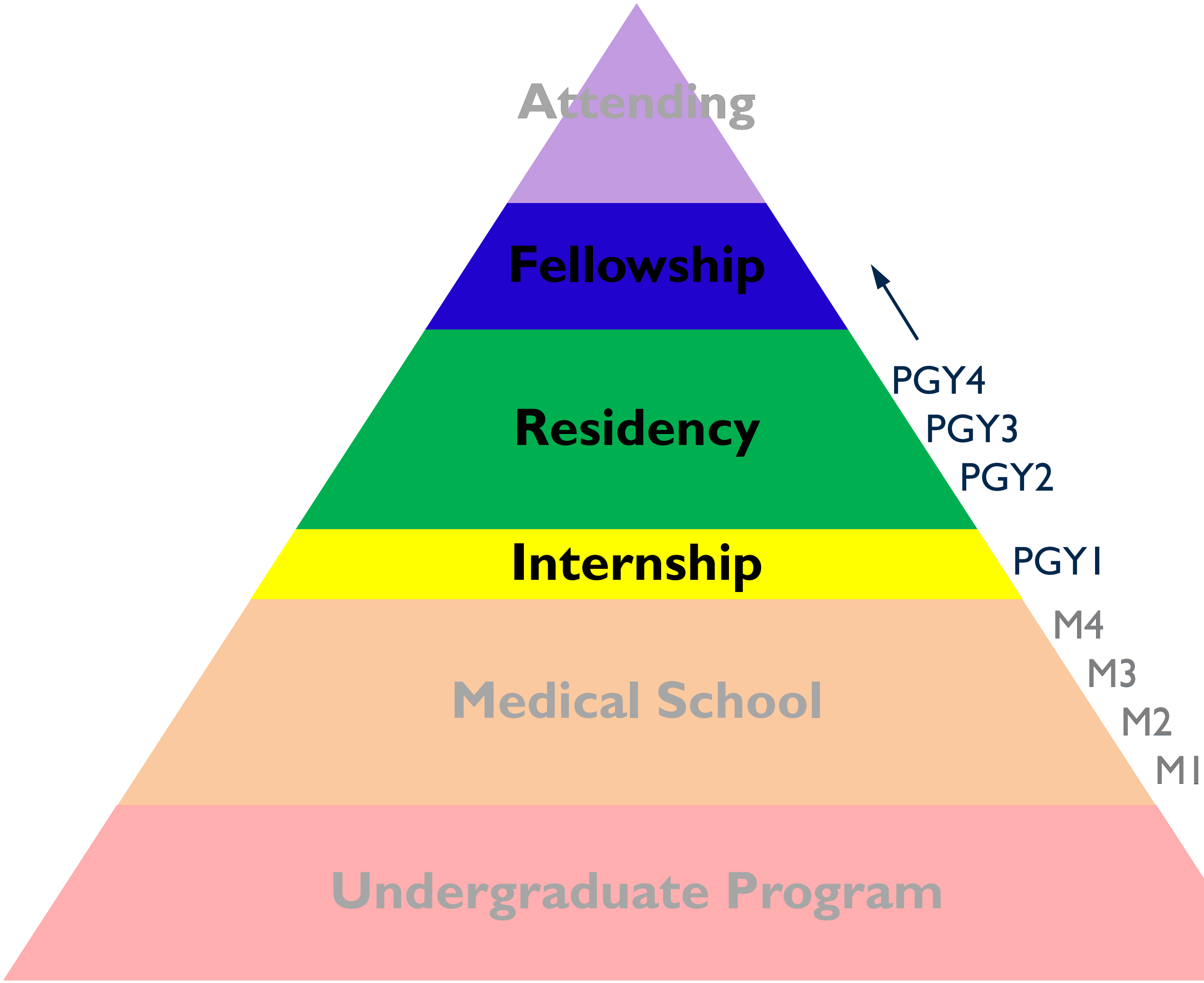
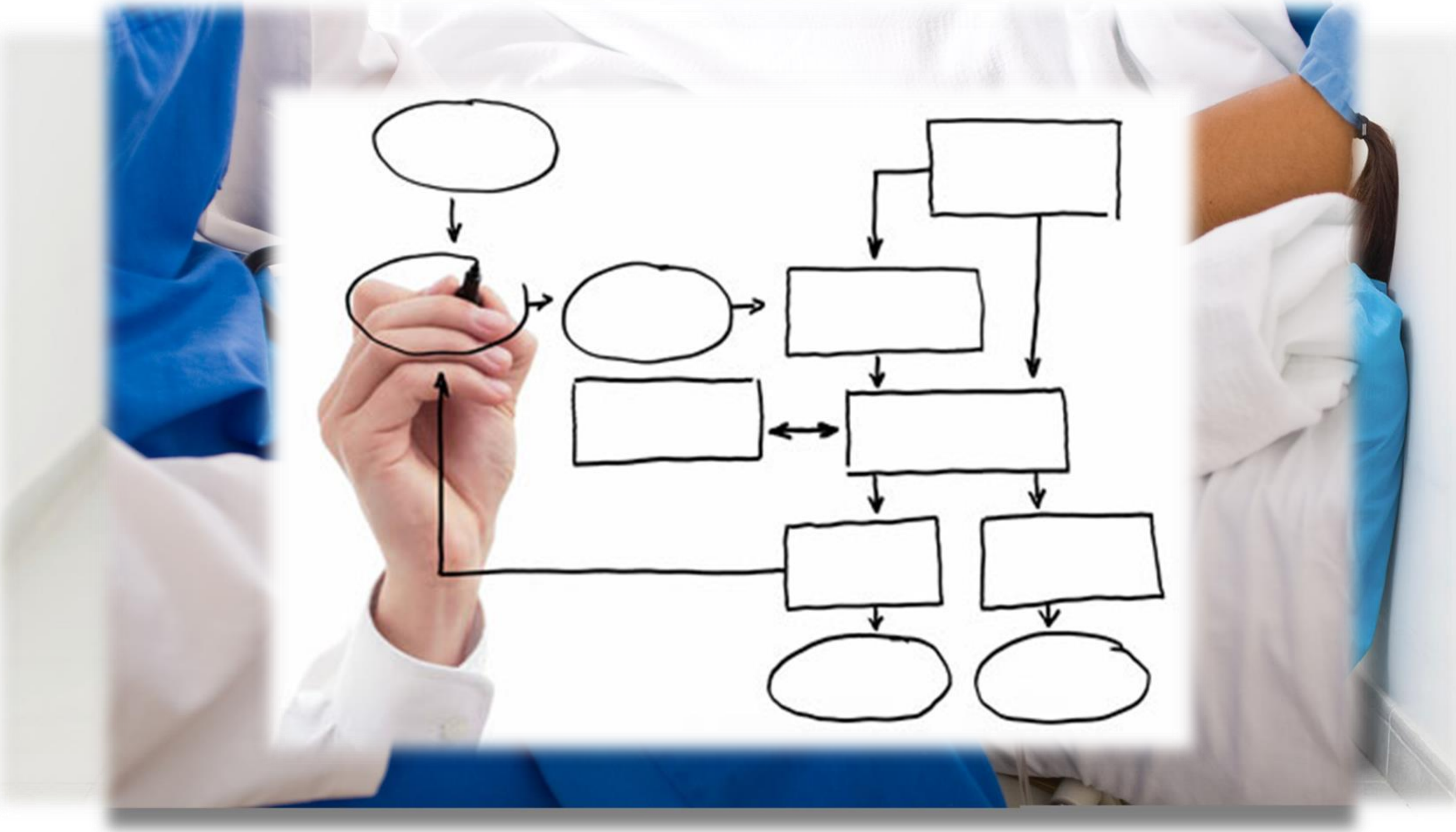
Healthcare Training Basics



Healthcare Training at Michigan

Importance of Scheduling



Who does the Scheduling?

- Program dependent
  - Chief Resident
  - Faculty (Program Director)
  - Senior Administrative Staff

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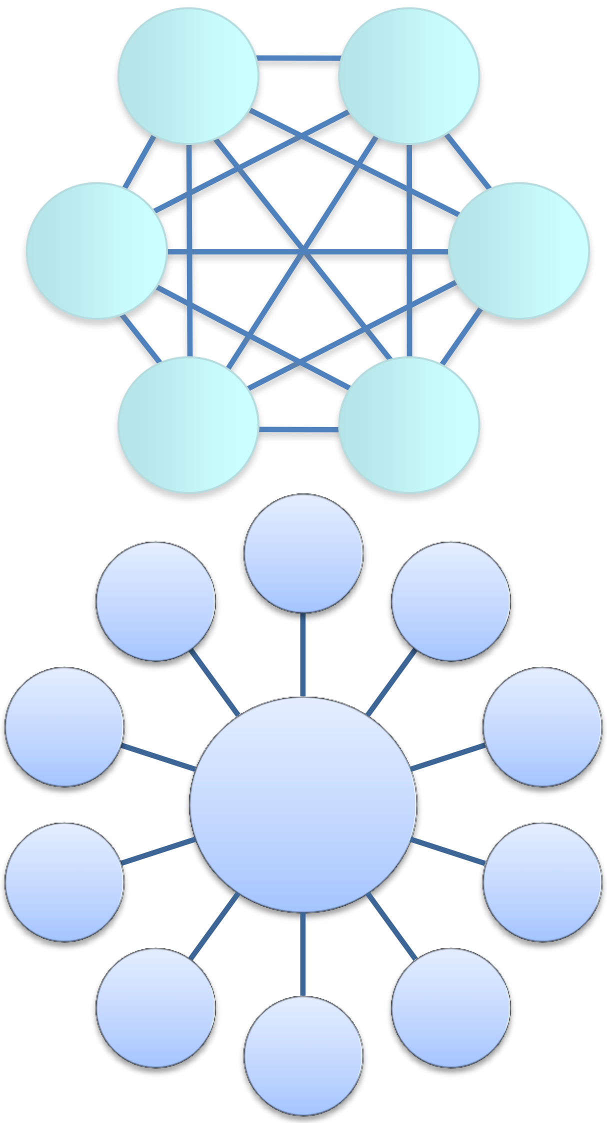
Challenges in Scheduling

- Time-intensive process
- Numerous stakeholders
- Complex rules and legal requirements
- Conflicting goals
- Varying strategies and interdependencies
- "Good enough" mentality



Resident Education Requirements

- Each program has unique educational requirements (operative and disease exposure)

	PGY1	PGY2	PGY3	PGY4	PGY5
1	MAIZE	MAIZE	MAIZE	MAIZE	MAIZE
2	BLUE	BLUE	BLUE	BLUE	
3	WHITE	WHITE	WHITE	WHITE	BLUE
4	MAIZE/BLUE/WHITE	MAIZE/BLUE/WHITE		ACS	
5	ACS	ACS	ACS		WHITE
6	DSP				
7	PLA	ANES	DSP		ACS
8	SICU		FLOAT		
9	STX	DSP	SICU		STX
10	SVA	FLOAT	THS	ELECTIVE	SVA
11	VA CT	SICU	STX/SVA	FOOTE	VA GS
12	VA GS-VASC	VA GS-VASC	VA GS	VA GS-VASC	VA GS-VASC

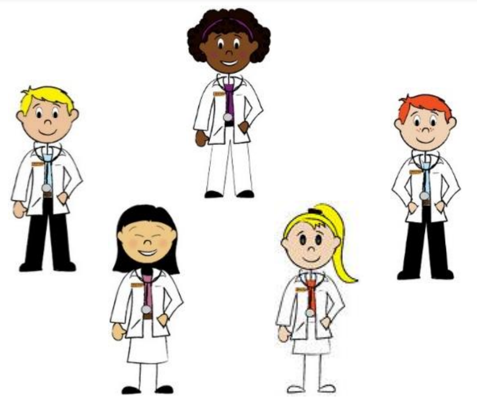
1–2	RED	GOLD	BLUE	VA	ACADEMIC	BLUE	RED
3–4	BLUE	HAND	ENT	BLUE		GOLD	
5–6	HAND	SJMH	SJMH	SJMH		RED	BLUE
7–8	TBE / GI SURG	DAY CSLT	GOLD	OP / OMFS		SJMH	
9–10	VA GS-VASC / VASC	RED / ORTHO	DAY CSLT / NIGHT CSLT	NIGHT CSLT		HAND	GOLD
11–12	STX / PEDS SURG	TBE / SICU	VASC / SURG ONC	RED		HAND	

PGY6 PGY7

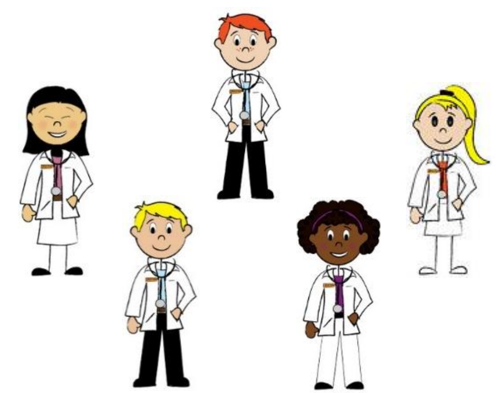
General Surgery / Plastic Surgery (… residents … fellows per level per year)

Service Coverage Requirements

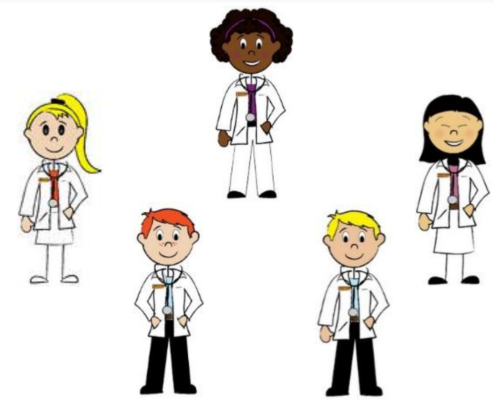
- Each service requires a resident complement comprised of varying skillsets and disciplines



1ST YEAR GENERAL SURG



1ST YEAR PLASTIC SURG



1ST YEAR VASCULAR SURG

WHITE

SICU

STX

Traditional Scheduling Approach

1. Build rotation templates
2. Adjust for coverage and educational needs
3. Renegotiate after reaching a dead-end

JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APRIL	MAY	JUNE
BLUE	MAIZE	PLA	SVA	SICU	BLUE	WHITE	PLA	STX	VA G&V	VA CT	DSP
VA G&V	PLA	MAIZE	WHITE	ACS	BLUE	SICU	BLUE	PLA	STX	STX	VA CT
VA CT	PLA	BLUE	DSP	VA G&V	ACS	SICU	BLUE	MAIZE	WHITE	SVA	SVA
MAIZE	VA CT	VA G&V	BLUE	SVA	WHITE	ACS	SICU	BLUE	STX	PLA	DSP

Project Goal

Design a linear program which automates creation of a block schedule that satisfies the needs of the residents and services.

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Linear Programming Basics

- A technique to solve complicated story problems
- Four basic parts
  - Sets and parameters
  - Decision variables
  - Objective function
  - Constraints

$$\min \quad 2x_1 + x_2$$

subject to

$$\begin{aligned} x_1 + x_2 &\geq 5 \\ 2x_1 + 3x_2 &\leq 11 \\ x_1, x_2 &\geq 0 \end{aligned}$$

Optimal Solution: (1, 4)
Objective Value = 6

Sets

R: residents

C: resident categories

S: services

M: months

Parameters

$a_{rc} \in \{0, 1\}$: indicates if resident $\boldsymbol{r}$ fits category $\boldsymbol{c}$

$\mathcal{L}_{csm}$: lower bound on number of residents fitting category $\boldsymbol{c}$ in service $\boldsymbol{s}$ during month $\boldsymbol{m}$

$\mathcal{U}_{csm}$: upper bound on number of residents fitting category $\boldsymbol{c}$ in service $\boldsymbol{s}$ during month $\boldsymbol{m}$

λ_{rs}: lower bound on number of months resident $\boldsymbol{r}$ must spend on service $\boldsymbol{s}$

μ_{rs}: upper bound on number of months resident $\boldsymbol{r}$ must spend on service $\boldsymbol{s}$

Decision Variables

$x_{rsm} \in \{0, 1\}$: whether resident $\boldsymbol{r}$ is assigned to service $\boldsymbol{s}$ in month $\boldsymbol{m}$

$$\forall\, r \in R, s \in S, m \in M$$

The base model does not have an objective function.

Constraints

1. Every resident gets assigned to one service every month

$$\sum_{s \in S} x_{rsm} = 1, \qquad \forall\, r \in R, m \in M$$

2. Every resident satisfies their educational requirements

$$\lambda_{rs} \leq \sum_{m \in M} x_{rsm} \leq \mu_{rs}, \qquad \forall\, r \in R, s \in S$$

3. Every service satisfies their service coverage needs

$$\mathcal{L}_{csm} \leq \sum_{r \in R} a_{rc} x_{rsm} \leq \mathcal{U}_{csm}, \qquad \forall\, c \in C, s \in S, m \in M$$

$\vdots$

Constraints

1. Every resident gets assigned to one service every month

$x_{Smith,Maize,July}$ Is Dr. Smith assigned to the Maize service in July?

If yes, $x_{Smith,Maize,July} = 1$. If no, $x_{Smith,Maize,July} = 0$.

$x_{Smith,Blue,July}$ Is Dr. Smith assigned to the Blue service in July?

$x_{Smith,White,July}$ Is Dr. Smith assigned to the White service in July?

$$x_{Smith,Maize,July} + x_{Smith,Blue,July} + x_{Smith,White,July} = 1$$

Constraints

1. Every resident gets assigned to one service every month

$$x_{Smith,Maize,July} + x_{Smith,Blue,July} + x_{Smith,White,July} = 1$$

$$x_{Smith,Maize,Aug} + x_{Smith,Blue,Aug} + x_{Smith,White,Aug} = 1$$

$$\vdots$$

$$x_{Smith,Maize,June} + x_{Smith,Blue,June} + x_{Smith,White,June} = 1$$

$$x_{Jones,Maize,July} + x_{Jones,Blue,July} + x_{Jones,White,July} = 1$$

$$\vdots$$

$$x_{Jones,Maize,June} + x_{Jones,Blue,June} + x_{Jones,White,June} = 1$$

$$\boldsymbol{\sum_{s \in S} x_{rsm} = 1, \qquad \forall\, r \in R, m \in M}$$

Constraints

2. Every resident satisfies their educational requirements

$x_{Smith,Maize,July}$ Is Dr. Smith assigned to the Maize service in July?

If yes, $x_{Smith,Maize,July} = 1$. If no, $x_{Smith,Maize,July} = 0$.

$x_{Smith,Maize,Aug}$ Is Dr. Smith assigned to the Maize service in August?

$\vdots$

$x_{Smith,Maize,June}$ Is Dr. Smith assigned to the Maize service in June?

$$1 \leq x_{Smith,Maize,July} + x_{Smith,Maize,Aug} + \ldots + x_{Smith,Maize,June} \leq 2$$

Constraints

2. Every resident satisfies their educational requirements

$$1 \leq x_{Smith,Maize,July} + x_{Smith,Maize,Aug} + \ldots + x_{Smith,Maize,June} \leq 2$$

$$1 \leq x_{Smith,Blue,July} + x_{Smith,Blue,Aug} + \ldots + x_{Smith,Blue,June} \leq 2$$

$$1 \leq x_{Smith,White,July} + x_{Smith,White,Aug} + \ldots + x_{Smith,White,June} \leq 2$$

$$1 \leq x_{Jones,Maize,July} + x_{Jones,Maize,Aug} + \ldots + x_{Jones,Maize,June} \leq 2$$

$$\vdots$$

$$1 \leq x_{Jones,Blue,July} + x_{Jones,Blue,Aug} + \ldots + x_{Jones,Blue,June} \leq 2$$

$$\boldsymbol{\lambda_{rs} \leq \sum_{m \in M} x_{rsm} \leq \mu_{rs}, \qquad \forall\, r \in R, s \in S}$$

Constraints

3. Every service satisfies their service coverage needs

$x_{Smith,Maize,July}$ Is Dr. Smith assigned to the Maize service in July?

If yes, $x_{Smith,Maize,July} = 1$. If no, $x_{Smith,Maize,July} = 0$.

$a_{Smith,GS}$ Is Dr. Smith a General Surgery resident?

If yes, $a_{Smith,GS} = 1$. If no, $a_{Smith,GS} = 0$.

$a_{Smith,PGY1}$ Is Dr. Smith a PGY1 resident?

If yes, $a_{Smith,PGY1} = 1$. If no, $a_{Smith,PGY1} = 0$.

a_{Smith,GS_PGY1} Is Dr. Smith a General Surgery PGY1 resident?

If yes, $a_{Smith,GS\_PGY1} = 1$. If no, $a_{Smith,GS\_PGY1} = 0$.

Constraints

3. Every service satisfies their service coverage needs

$$3 \leq a_{Smith,GS}x_{Smith,Maize,July} + a_{Jones,GS}x_{Jones,Maize,July} + a_{Chan,GS}x_{Chan,Maize,July} + \ldots + a_{Gupta,GS}x_{Gupta,Maize,July} \leq 4$$

$$1 \leq a_{Smith,PGY1}x_{Smith,Maize,July} + a_{Jones,PGY1}x_{Jones,Maize,July} + a_{Chan,PGY1}x_{Chan,Maize,July} + \ldots + a_{Gupta,PGY1}x_{Gupta,Maize,July} \leq 2$$

$$\boldsymbol{\mathcal{L}_{csm}} \leq \sum_{\boldsymbol{r \in R}} \boldsymbol{a_{rc} x_{rsm}} \leq \boldsymbol{\mathcal{U}_{csm}}, \qquad \forall\, \boldsymbol{c \in C, s \in S, m \in M}$$

Expanded Model

- Distributed Educational Requirements
- Distributed Coverage Needs
- Extended Rotations
- Service Sequencing
- Service Spacing
- Resident Pairing

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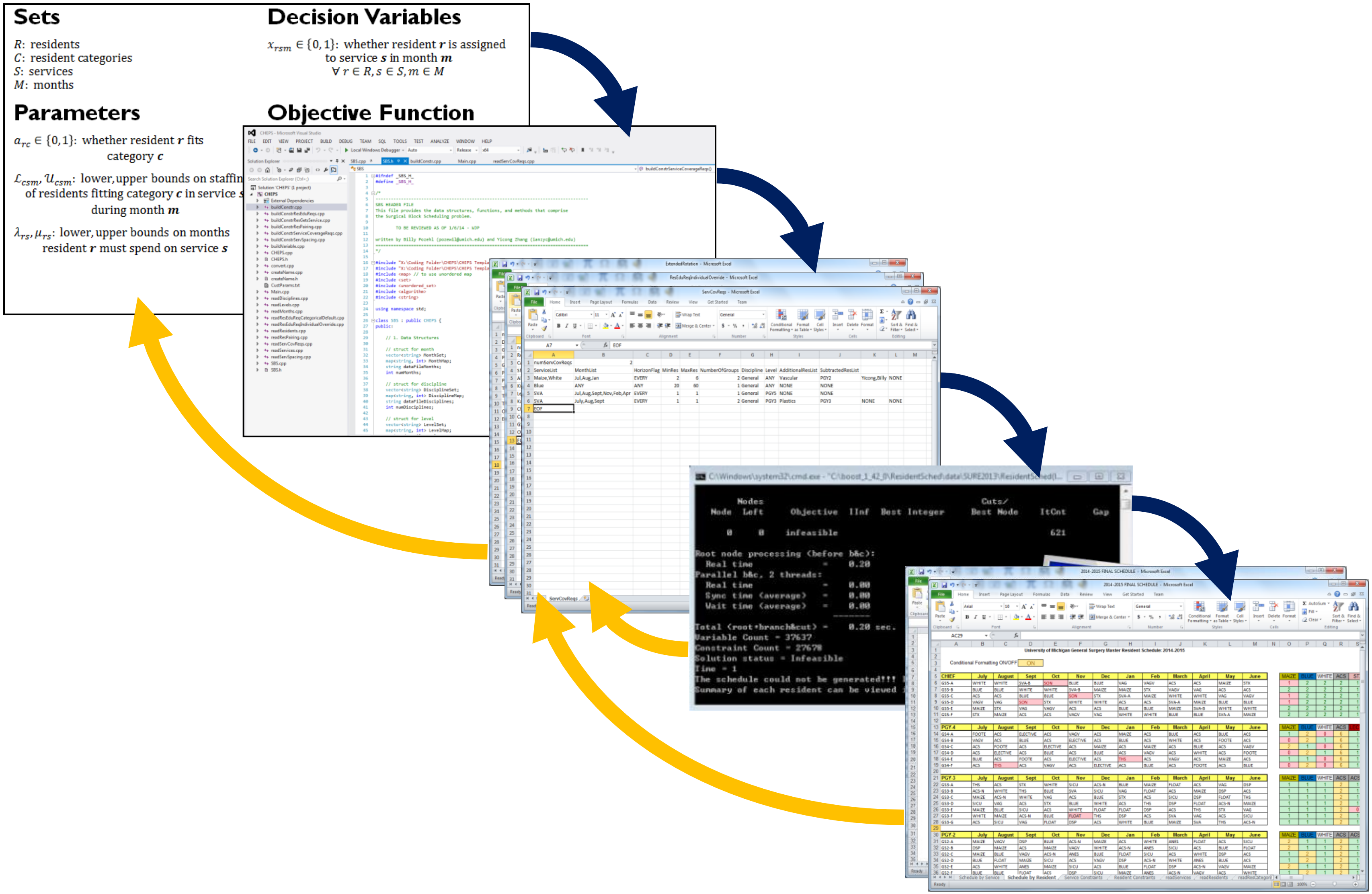
Implementation Process



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Recap

- Scheduling issues affect hospital workflow, training quality, and patient safety
- Scheduling residency programs at UMHS is highly interdependent, complex, and poorly executed
- We can address these scheduling needs using a linear programming formulation

Future Work

- Define metrics for schedule optimality
  – Minimize deviation from desired resident complement by service
  – Maximize satisfied requests for educational customization
- Apply model to improve scheduling for other training programs

Related Applications

- Pediatric Medicine rotation schedule
- C.S. Mott Emergency Department shift schedule
- Chemotherapy infusion patient schedule
- Physician clinic/OR schedule
- Master surgical schedule problem
- Nurse staff scheduling

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Questions [?] and Comments [!]

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