On Measuring, Modeling and Analyzing Healthcare Systems in Real-Time

From Small Measurements through Big Data to Analytics

Avi Mandelbaum

IE&M **SEE Laboratory**

Technion, Haifa, Israel

http://ie.technion.ac.il/serveng

T2med Technion, December 2013

- **Lecture will be downloadable from my Technion website**

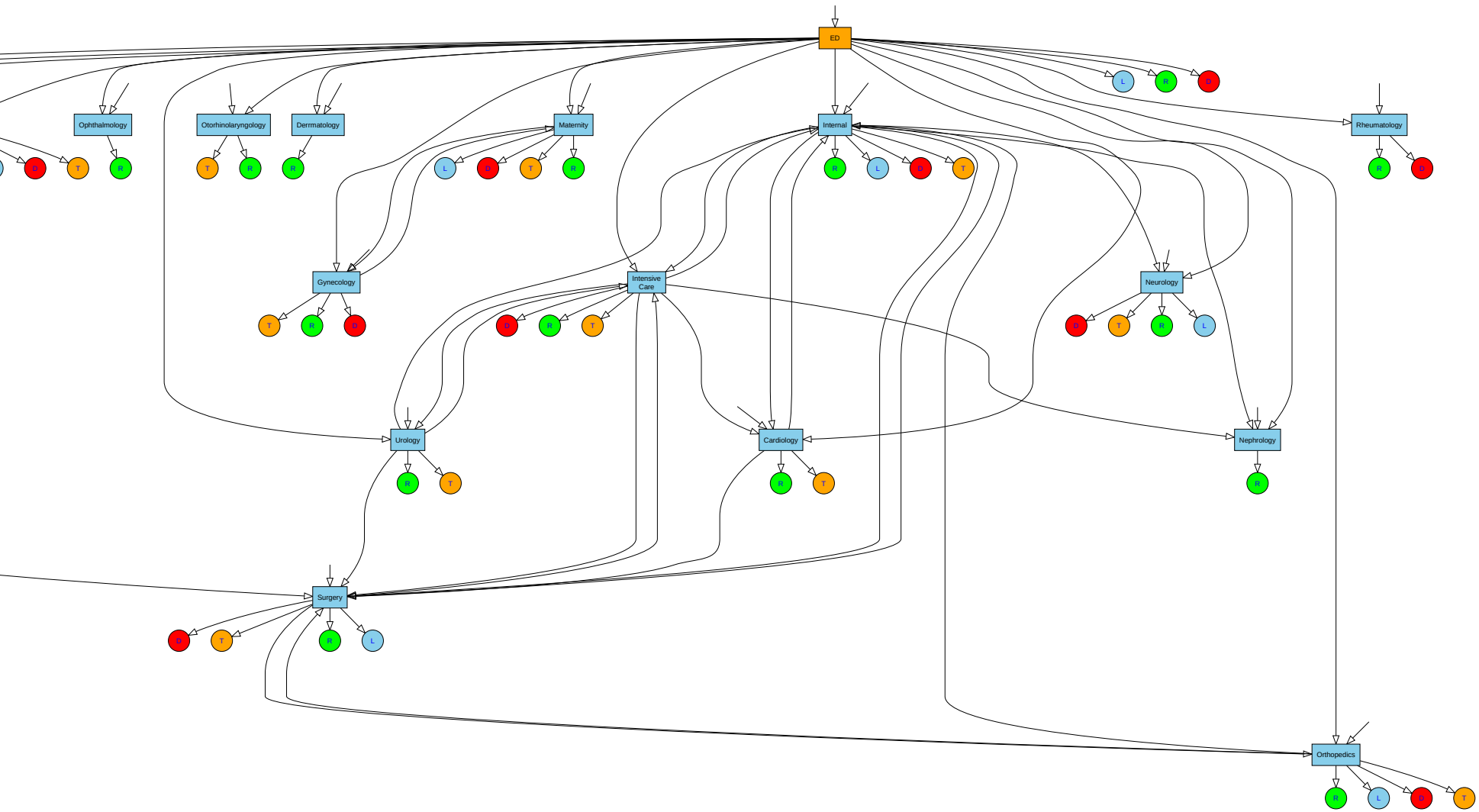
ED-Environment in Israel

Queueing in a “Good" Hospital

Tong-ren Hospital at 6am, Beijing

Hospital Network: Inter-Ward Patient Flow

Patients movement (HomeHospital)
January 2005



Research Partners

- **Students**:
  Aldor*, Baron Yonit*, Carmeli*, Chen Hong*, Cohen Izik*, Feldman Zohar*, Garnett*, Gurvich*, Khudiakov*, Koren, Maman*, Marmor*, Reich*, Rosenshmidt*, Shaikhet*, Senderovic*, Tseytlin*, Yom-Tov*, Yuviler, Zaied*, Zeltyn*, Zychlinski*, Zohar Eti*, Zviran*, . . .
- **Theory**:
  Armony, Atar, Azriel, Cohen Izik, Gurvich, Feigin, Huang Junfei, Jelenkovic, Kaspi, Massey, Momcilovic, Reiman, Shimkin, Stolyar, Trofimov, Wasserkrug, Whitt, Zeltyn, Zhang Jiheng, Zhang Hanqin [1] , . . .
- **Empirical/Statistical Analysis**:
  Brown, Gans, Shen Haipeng, Zhao Linda; Zeltyn; Ritov, Goldberg; Gurvich, Huang Junfei, Liberman; Liu Nan, Ye Han; Armony, Marmor, Tseytlin, Yom-Tov; Gorfine, Ghebali; Feigin, Azriel; Tezcan; Kim Song-Hee, Won Chul Cha; He Shuangchi, Sim Melvyn . . .
- **Industry**:
  Mizrahi Bank, Fleet Bank, Rambam Hospital, IBM Research, Hapoalim Bank, Pelephone Cellular, Samsung Hospital, . . .
- **Technion SEE Center / Laboratory**:
  Feigin; Trofimov, Nadjharov, Gavako, Kutsy; Senderovic; Liberman, Koren, Plonsky; Research Assistants, . . .

[1] In many Western countries, there is a short list of popular “first names," but countless “last names." In China, it is just the reverse. The list of last names is short, and the number of first names is in the billions (from chinapage.com/biography/lastname.html).

Research Goals

- Reality: Service Systems
  e.g. **Hospitals, Call Centers**, Websites, . . .

- Models = **ServNets**

  Simple models at the service of complex realities

  Q-Nets, F-Nets, D-Nets, Sim-Nets: Operations Research (Math)

  but also **P-Nets, C-Nets**, **. . .**, as in BPM, WFM, Process Mining

Research Goals

- Reality: Service Systems
  e.g. **Hospitals, Call Centers**, Websites, . . .

- Models = **ServNets**

  Simple models at the service of complex realities

  Q-Nets, F-Nets, D-Nets, Sim-Nets: Operations Research (Math)

  but also **P-Nets, C-Nets**, **. . .**, as in BPM, WFM, Process Mining

- Research: **Data-based Modeling, Analysis, Optimization**

Research Goals

- Reality: Service Systems
  e.g. **Hospitals, Call Centers**, Websites, . . .
- Models = **ServNets**

  Simple models at the service of complex realities

  Q-Nets, F-Nets, D-Nets, Sim-Nets: Operations Research (Math)

  but also **P-Nets, C-Nets**, **. . .**, as in BPM, WFM, Process Mining
- Research: **Data-based Modeling, Analysis, Optimization**
- Goals: (Reproducible) research & teaching (that impact practice)

$\Rightarrow$ **Data & analysis** of ServNets: **accessible, useful**

$\Rightarrow$ **Model creation & validation: automatic, real-time, data-based**

Feasible? Why be Optimistic?

e.g. Emergency Department models & analysis
On-demand, Automatic:

- Real-time: **control** patient-flow bottlenecks
- Short-term: on Monday, set Tuesday's **staffing** levels (or next week's)
- **Design**: Physician protocol – explore (triage) vs. exploit (discharge)

Technion IE&M research (OR/QS/IE) + **SEELab** technologies:

- **Operational recipes** (control, staffing, design) via **Math-Nets** (Q, F, D)

Feasible? Why be Optimistic?

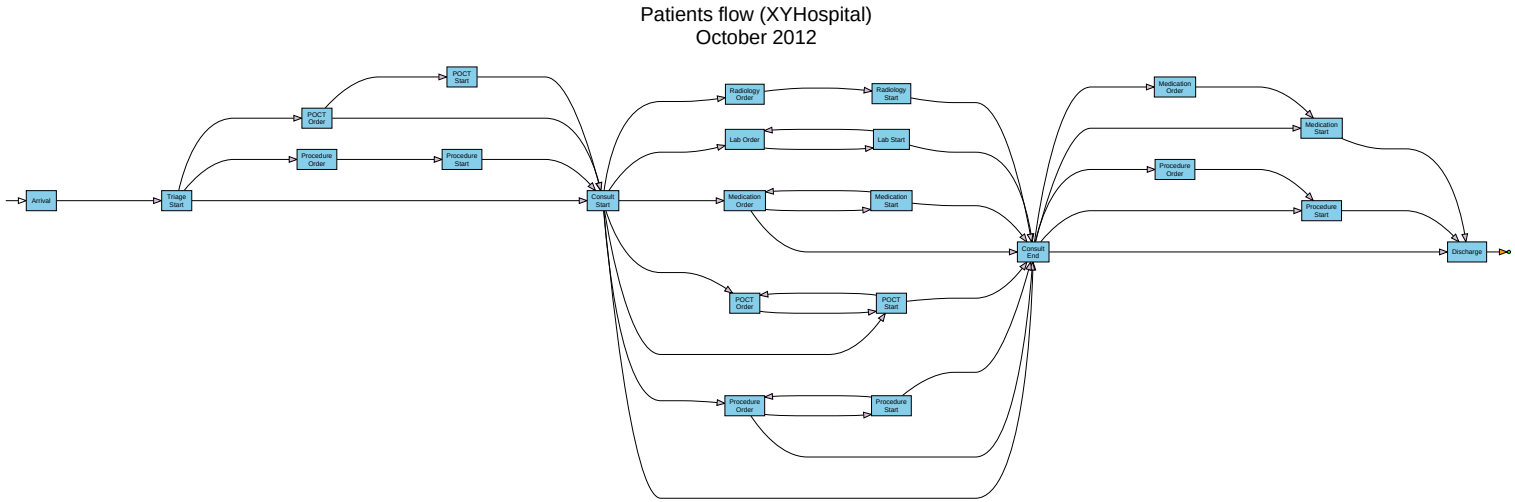
e.g. Emergency Department models & analysis
On-demand, Automatic:

- Real-time: **control** patient-flow bottlenecks
- Short-term: on Monday, set Tuesday's **staffing** levels (or next week's)
- **Design**: Physician protocol – explore (triage) vs. exploit (discharge)

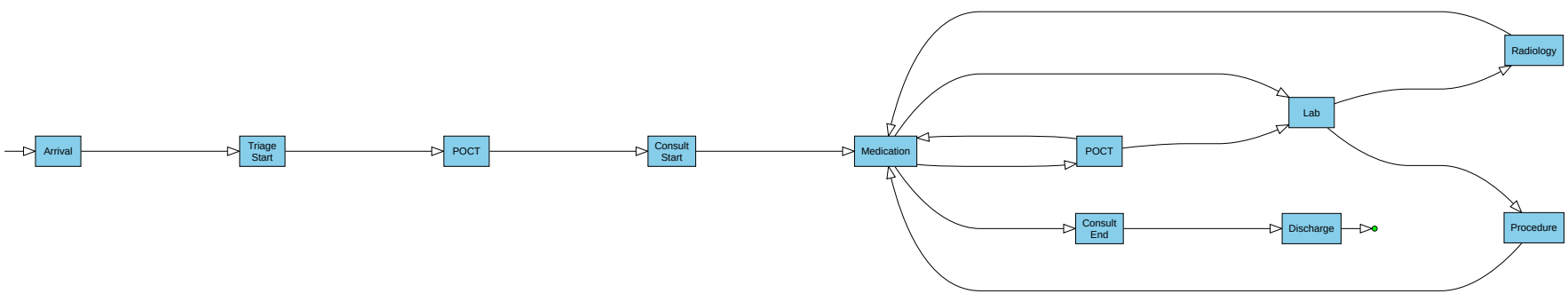
Technion IE&M research (OR/QS/IE) + **SEELab** technologies:

- **Operational recipes** (control, staffing, design) via **Math-Nets** (Q, F, D)
- **Virtual realities** (validation labs) via **SimNets**
- **Process Mining** (Discovery, Conformance) of ServNets
  (Started w/ **A. Gal, A. Senderovic, M. Weidlich**)

Recurrent Service Process in the ED



Capture **Recurrent** nature of service process: **Multiple doctor visits**



Feasible? Why be Optimistic?

e.g. Emergency Department models & analysis
On-demand, Automatic:

- Real-time: **control** patient-flow bottlenecks
- Short-term: on Monday, set Tuesday's **staffing** levels (or next week's)
- **Design**: Physician protocol – explore (triage) vs. exploit (discharge)

Technion IE&M research (OR/QS/IE) + **SEELab** technologies:

- **Operational recipes** (control, staffing, design) via **Math-Nets** (Q, F, D)
- **Virtual realities** (validation labs) via **SimNets**
- **Process Mining** (Discovery, Conformance) of ServNets
  (Started w/ **A. Gal, A. Senderovic, M. Weidlich**)

Overcome "curse of simplicity": "my models too simple to be credible"

- Enrich them when desired (research) or needed (practice)
- **Scrutinize** as in clinical trials: patient = simulation sample-path

Contents (if I had an hour)

1. **Data-based paradigm** (for me and interested colleagues): Operations Research, Industrial Engineering, Queueing Science
2. **Two simple (parsimonious) models**
   - **Emergency Department**: **Time-Varying**
     - **Mass Casualty Event**: QNet and FNet (2 hours) - **performance**
     - Normal: QNet, DNet and SimNet (over 1 day) - **staffing**
   - Call Center: **Stationary**
     - Q-Net and D-Net (piecewise stationary) - **congestion laws**
3. **Empirical adventures at the Technion IE&M SEELab**: Mining operational building blocks of ServNets
   - **Primitives**
   - **Structure**
   - **Protocols**

ER / ED Environment: Service Network

Acute (Internal, Trauma)

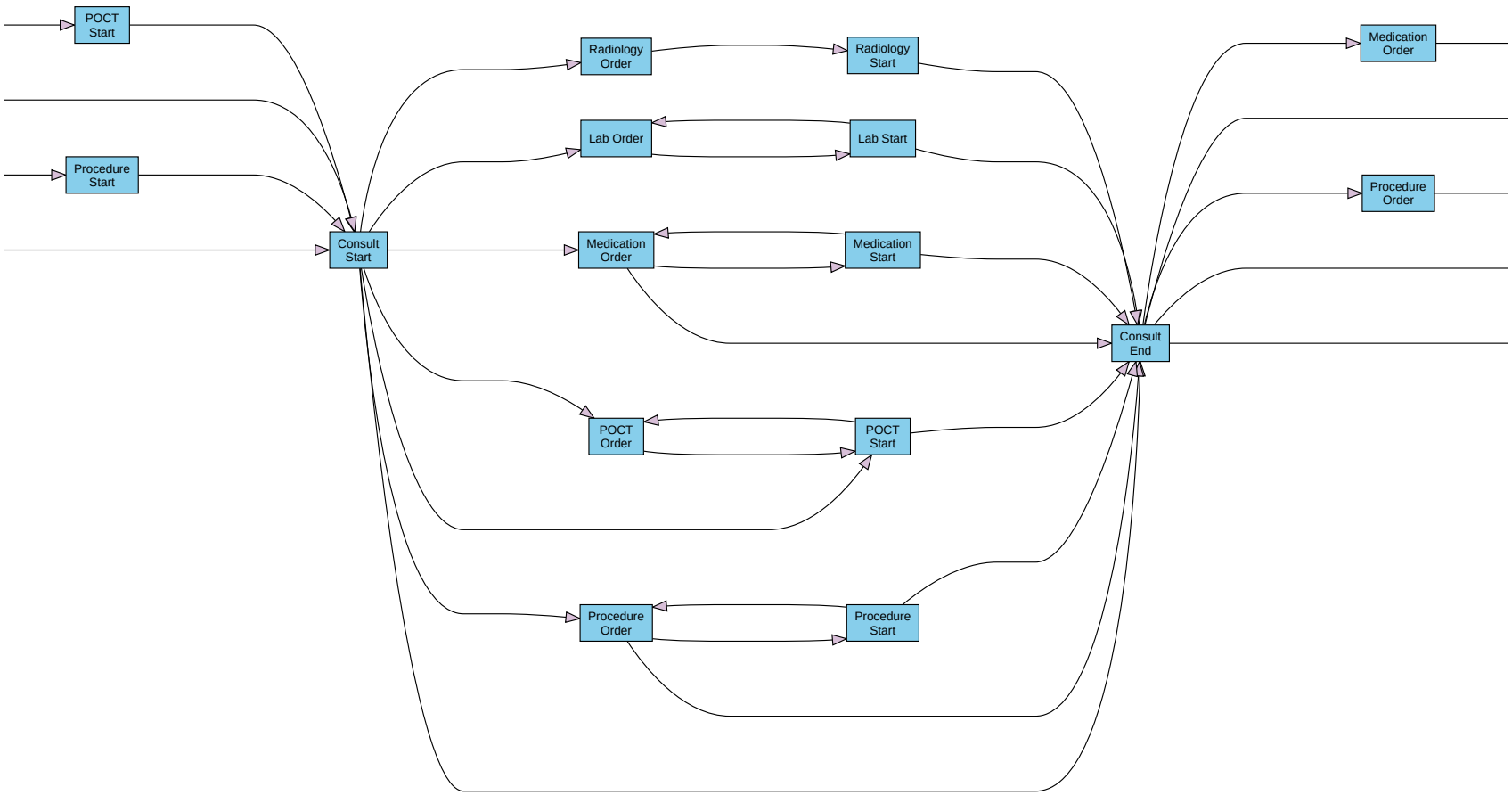
Walking

Multi-Trauma

Simple Models at the Service of Complex Realities: FNets

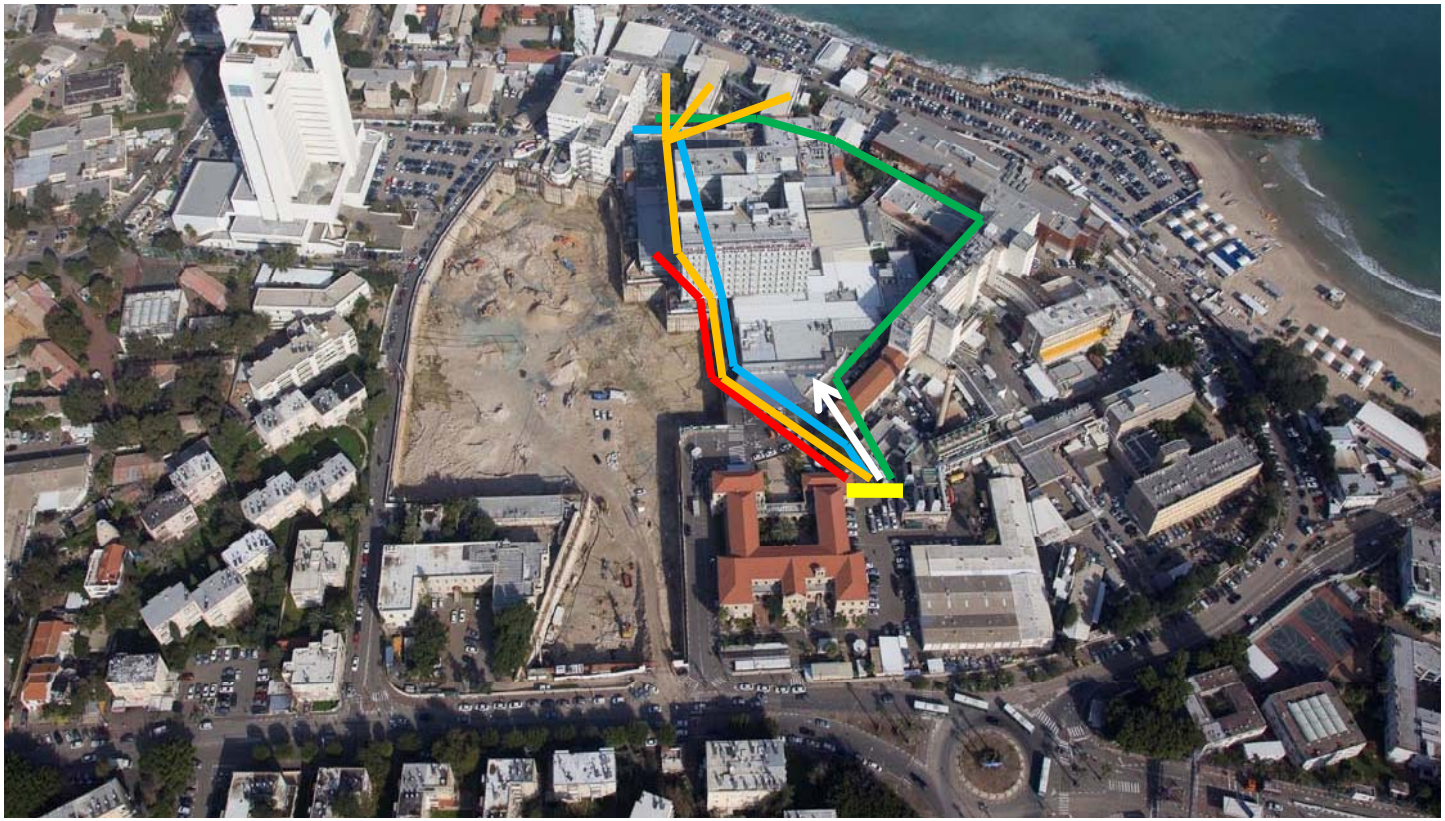
1. ED in Normal days (Time-Varying Periodic): Personnel Staffing (offline)
2. ED in **Mass Casualty Event** (**Transient**): Forecasting, Staffing (online)

Emergency Department in XYHospital, October 2012



RFID-Based Data in Mass Casualty Event (Drill)

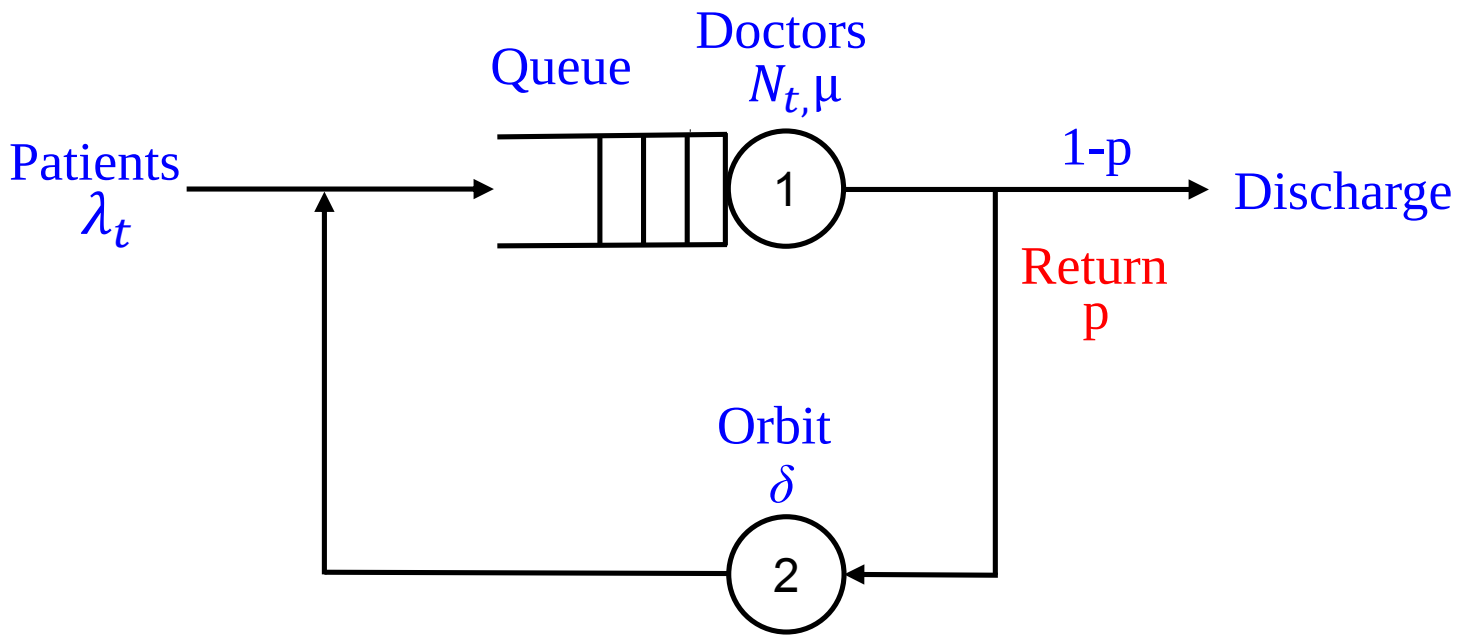
Chemical MCE, Rambam Hospital (May 2010, 11:00-13:00)



Fluid Model:

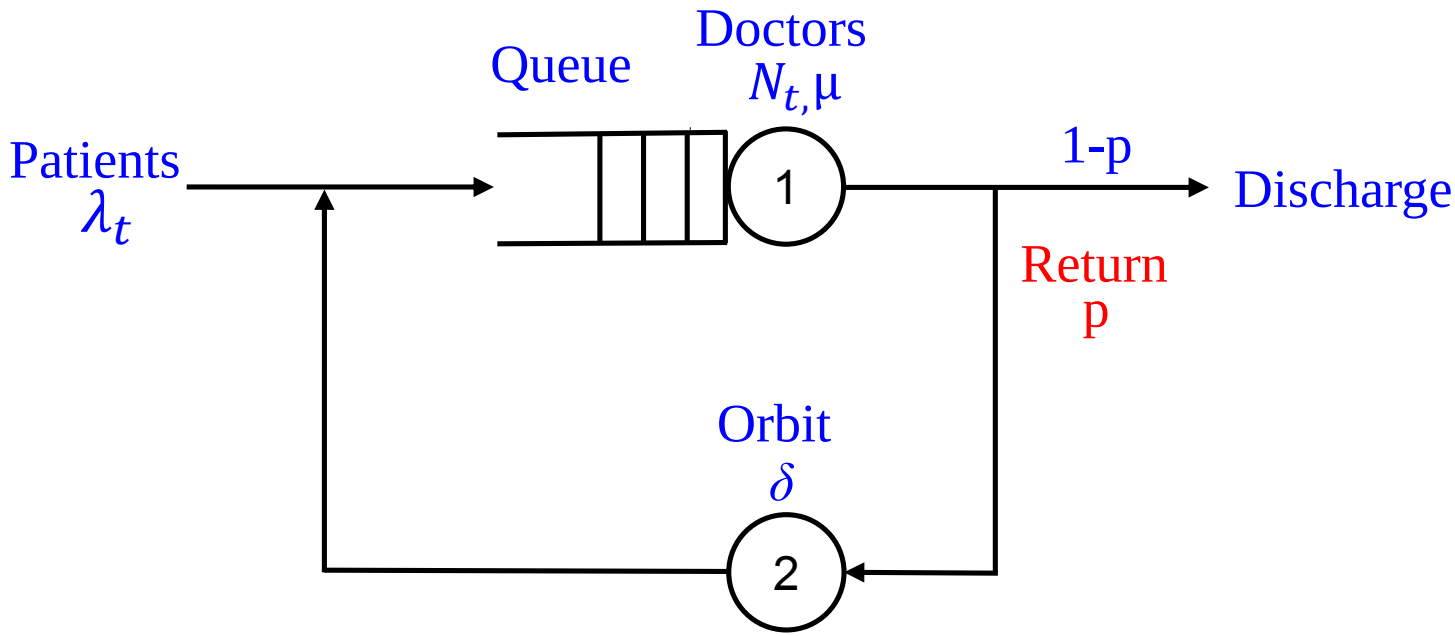
- **Predictable** Variability $\Rightarrow$ **Time-Varying**
- **Stochastic** Individualism averaged-out $\Rightarrow$ **Deterministic**

The Basic Service-Network Model: Erlang-R



w/ G. Yom-Tov

Fluid Model $\leftrightarrow$ (Time-Varying) Erlang-R System



Functional Strong Law of Large Numbers, for a 2-station QNet. BUT

FNet = ODE: derived **directly** (no QNet), spreadsheet "solution"

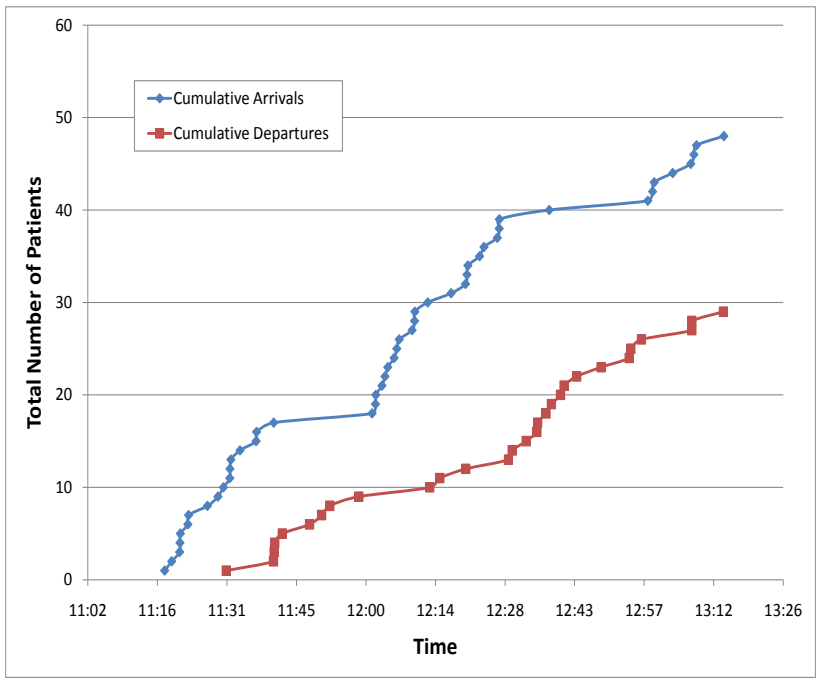
$$\frac{d}{dt} q_t^1 = \lambda_t - \mu \cdot (q_t^1 \wedge N_t) + \delta \cdot q_t^2$$

$$\frac{d}{dt} q_t^2 = p \cdot \mu \cdot (q_t^1 \wedge N_t) - \delta \cdot q_t^2$$

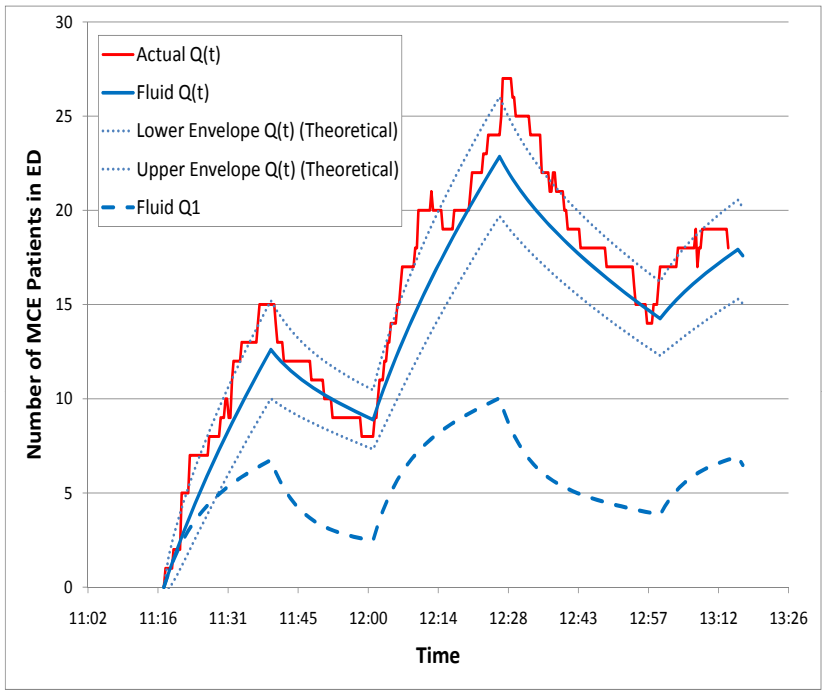
Erlang-R Value: FNet vs. Data

Chemical MCE Drill (Israel, May 2010, 11:00-13:00)

Arrivals & **Departures** (RFID)



Erlang-R (Fluid , Diffusion)



- **Recurrent/Repeated** services in Chemical MCE: injection every 15/30/60 min
- **Fluid** = ODE
- **Diffusion** (confidence band), via F. Central Limit Theorem: Usefully narrow

A Data-Based Framework, or “Erlang-R in the ED"

System = e.g. Emergency Department

- **QNet** = Erlang-R (time-varying 2-station Jackson; w/ Yom-Tov)
- **FNets** = 2-dim dynamical system (Massey & Whitt)
- **DNets** = 2-dim Markovian Service Net (w/ Massey and Reiman)
- **SimNet** = Customized ED-Simulator (Marmor & Sinreich)

Call-Center Environment: Service Network

= “Fruit-flies of Hospitals": fast, low-stake, no IRB, . . .

yet highly relevant: LWBS, flow control, staffing, data, . . .

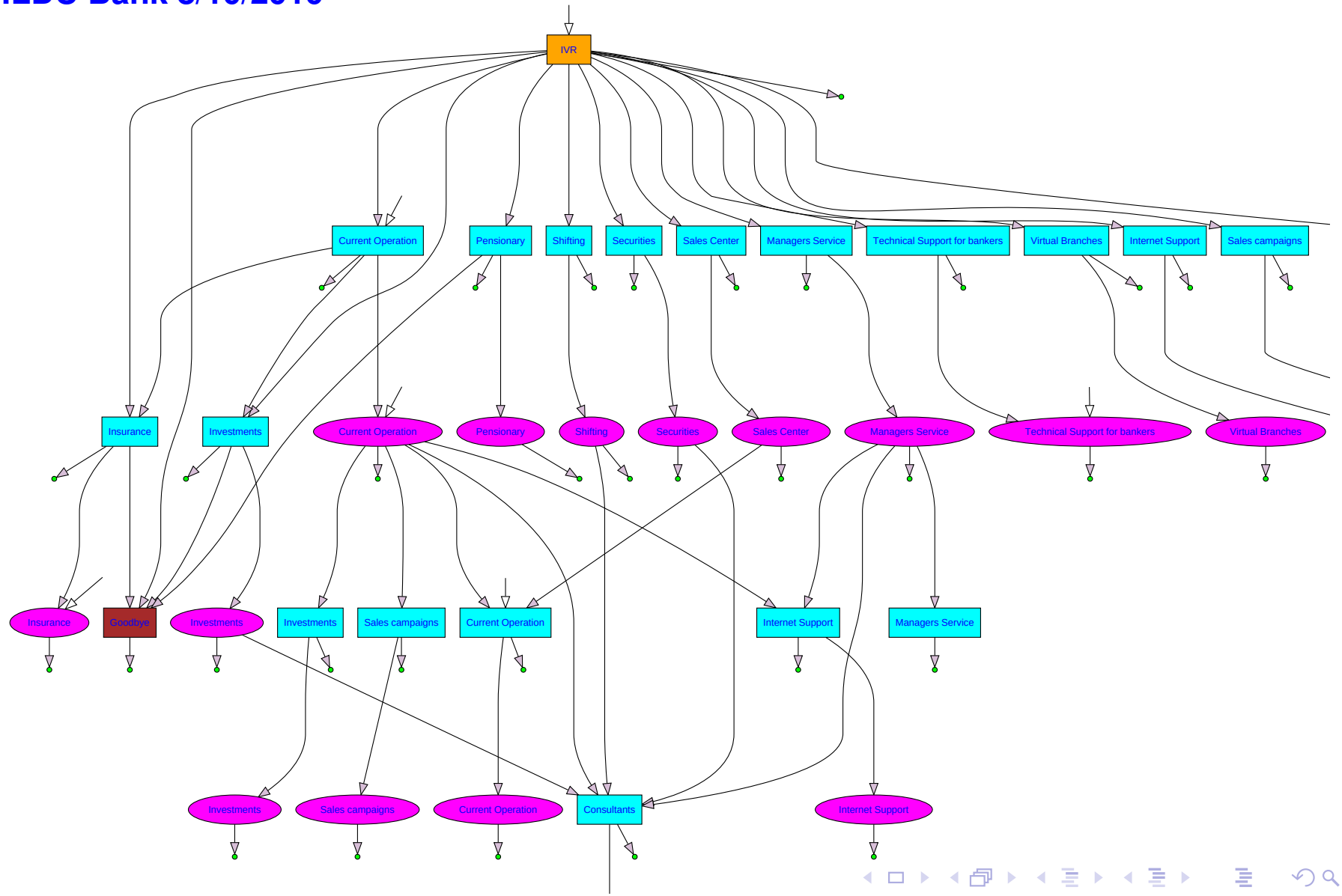
Operational Focus

Operational Measures:

- Surrogates for overall performance: Financial, Psychological; Clinical
- Easiest to quantify, measure, track online, react upon

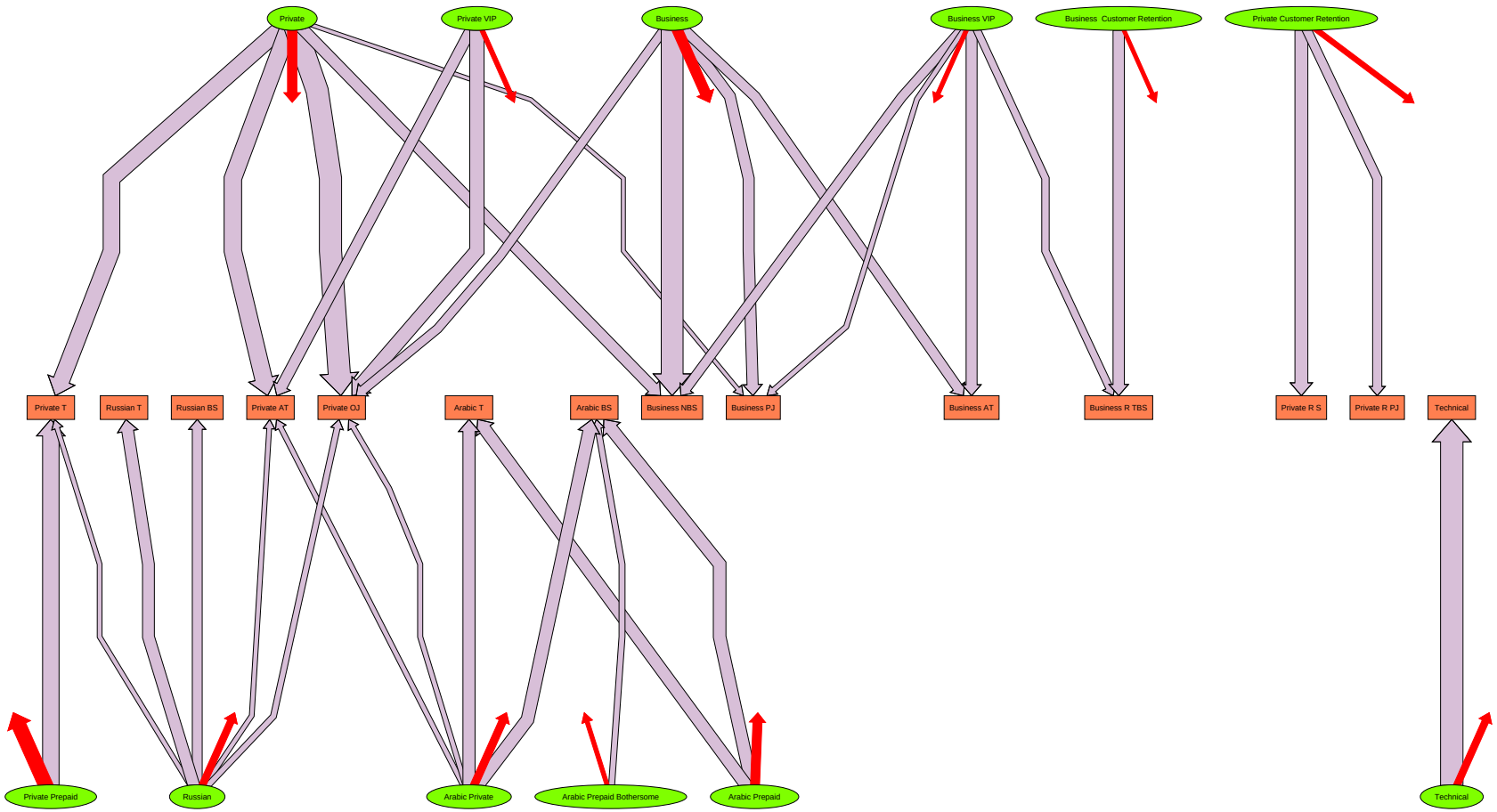
Customer Flow in Call Centers

ILDU Bank 8/10/2010



Impatient Customers - Isolate or Aggregate

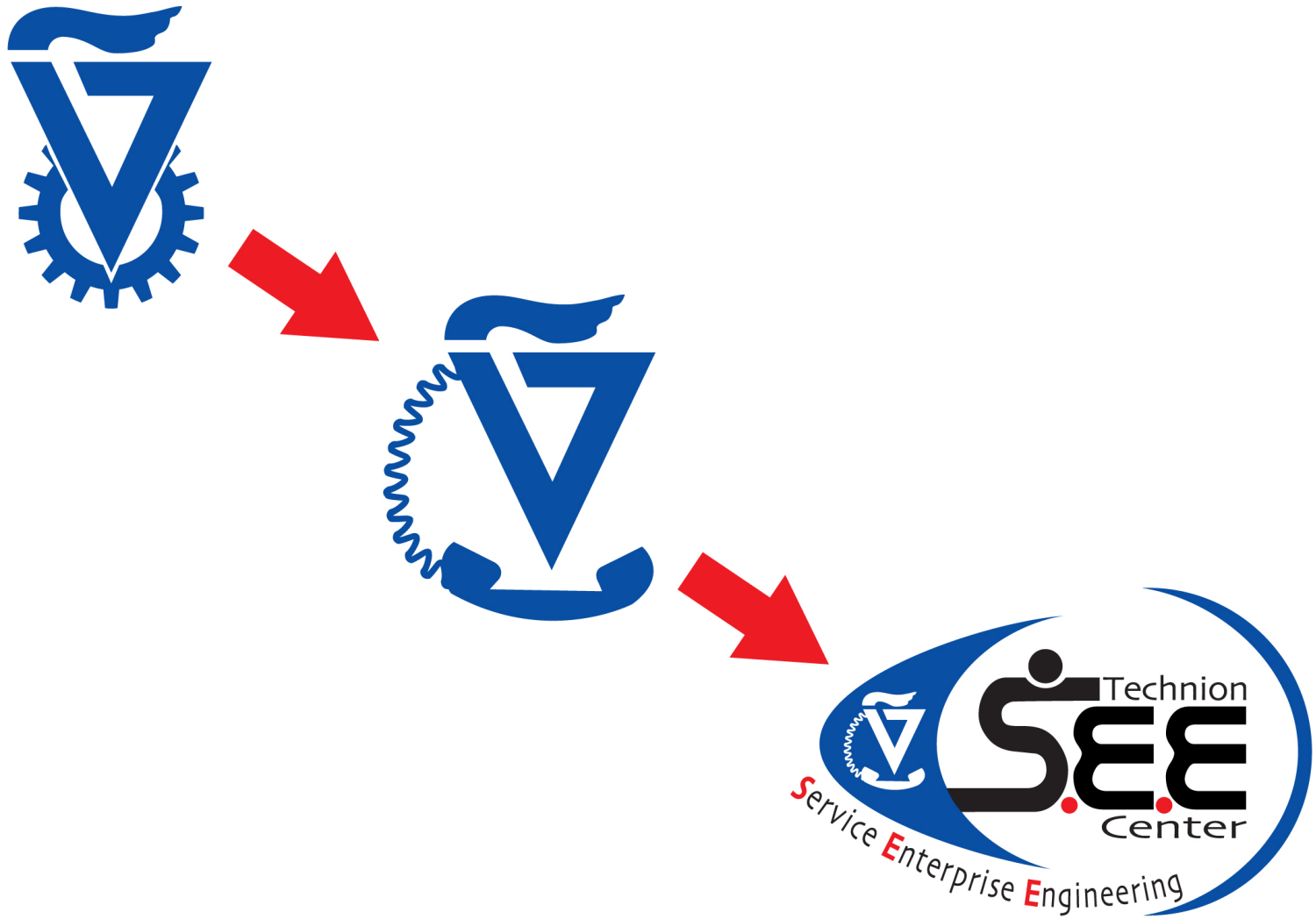
ILTelecom 9/3/2008



Pause for a Commercial:

Pause for a Commercial: The Technion SEELab

Hal and Inge Marcus (2007)



Technion SEE = Service Enterprise Engineering

SEELab: Environment for graphical EDA in real-time

- Detailed **operational histories** (customers, servers), e.g.
  1. * Bank Anonymous : **1 year, 350K calls by 15 agents** - in 2000, which paved the way to:
  2. *U.S. Bank : **2.5 years, 220M calls, 40M by 1000 agents**
  3. Israeli Cellular: **2.5 years, 110M calls, 25M calls by 750 agents**
  4. Israeli Bank: **from January 2010, daily-deposit at a SEESafe**
  5. Service Engineering **internet site**: click-stream data (2 years)

Technion SEE = Service Enterprise Engineering

SEELab: Environment for graphical EDA in real-time

- Detailed **operational histories** (customers, servers), e.g.
  1. * Bank Anonymous : **1 year, 350K calls by 15 agents** - in 2000, which paved the way to:
  2. *U.S. Bank : **2.5 years, 220M calls, 40M by 1000 agents**
  3. Israeli Cellular: **2.5 years, 110M calls, 25M calls by 750 agents**
  4. Israeli Bank: **from January 2010, daily-deposit at a SEESafe**
  5. Service Engineering **internet site**: click-stream data (2 years)
  6. *Home (Rambam) Hospital : **4 years, 1000 beds**, inter-ward flow
  7. **Emergency Department** (ED) patient flow:
     - 5 EDs in Israel: 1-2 years, **late David Sinreich**, ED arrivals & LOS
     - ED in Seoul: 2 months, **K. Song-Hee & W. Cha**, pilot
     - ED in XY: 2 years, pilot
  8. Hospital **RTLS** (Real-Time Location System), pilot:
     - **250K events/day: 1000 patients, 350 staff (1500 tagged entities)**
     - Infrastructure: **900 readers (sensors), many floors**

Technion SEE = Service Enterprise Engineering

SEELab: Environment for graphical EDA in real-time

- Detailed **operational histories** (customers, servers), e.g.
  1. * Bank Anonymous: **1 year, 350K calls by 15 agents** - in 2000, which paved the way to:
  2. *U.S. Bank: **2.5 years, 220M calls, 40M by 1000 agents**
  3. Israeli Cellular: **2.5 years, 110M calls, 25M calls by 750 agents**
  4. Israeli Bank: **from January 2010, daily-deposit at a SEESafe**
  5. Service Engineering **internet site**: click-stream data (2 years)
  6. *Home (Rambam) Hospital: **4 years, 1000 beds**, inter-ward flow
  7. **Emergency Department** (ED) patient flow:
     - 5 EDs in Israel: 1-2 years, **late David Sinreich**, ED arrivals & LOS
     - ED in Seoul: 2 months, **K. Song-Hee & W. Cha**, pilot
     - ED in XY: 2 years, pilot
  8. Hospital **RTLS** (Real-Time Location System), pilot:
     - **250K events/day: 1000 patients, 350 staff (1500 tagged entities)**
     - Infrastructure: **900 readers (sensors), many floors**

*** Open & Free for research and teaching**

Empirical Adventures at the SEELab

SEELab History suggests possible guidelines for ServNet Mining:

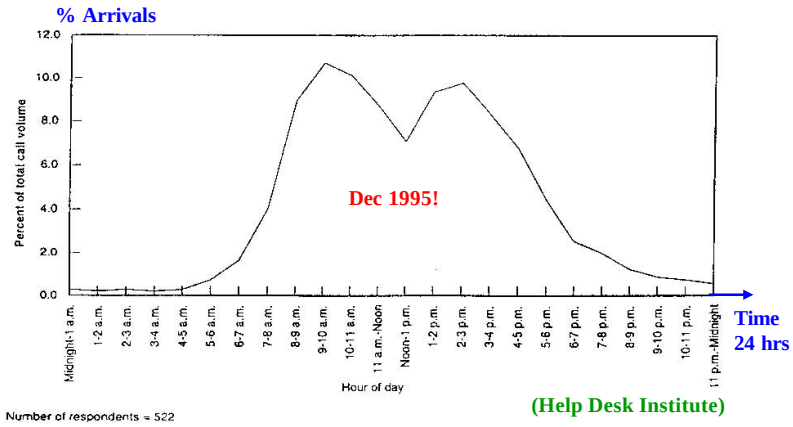
1. **Primitives**: arrivals, services, (im)patience
2. **Structure**: static process-maps
3. **Protocols**: Load Balancing, Dynamic Priority, Information

EDA $\Rightarrow$ open questions, new directions, uncharted territories

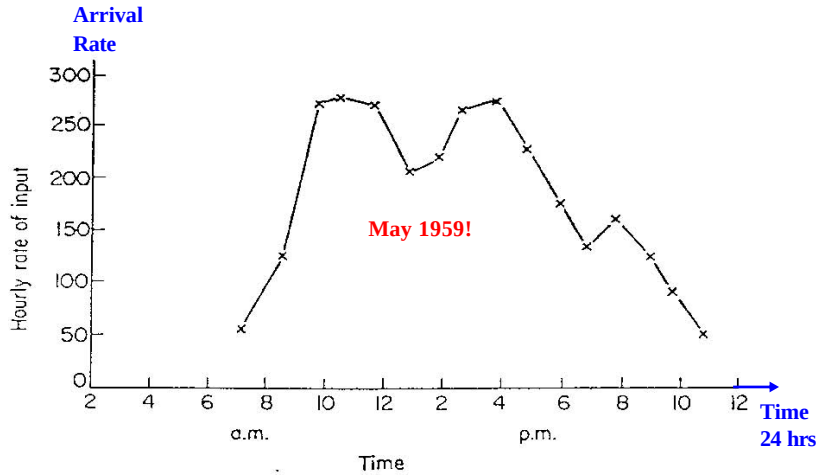
Primitives: Arrival (Rates) to Service

Why 2 Daily Peaks?

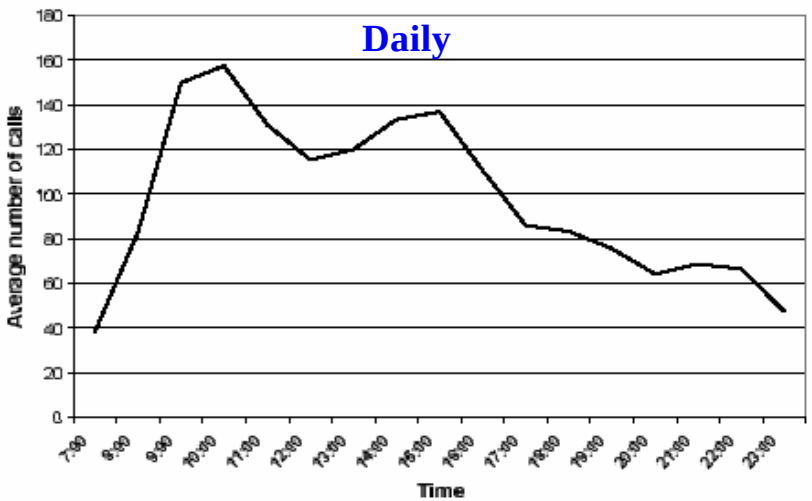
CC: Dec. **1995**, (USA, 700 Helpdesks)



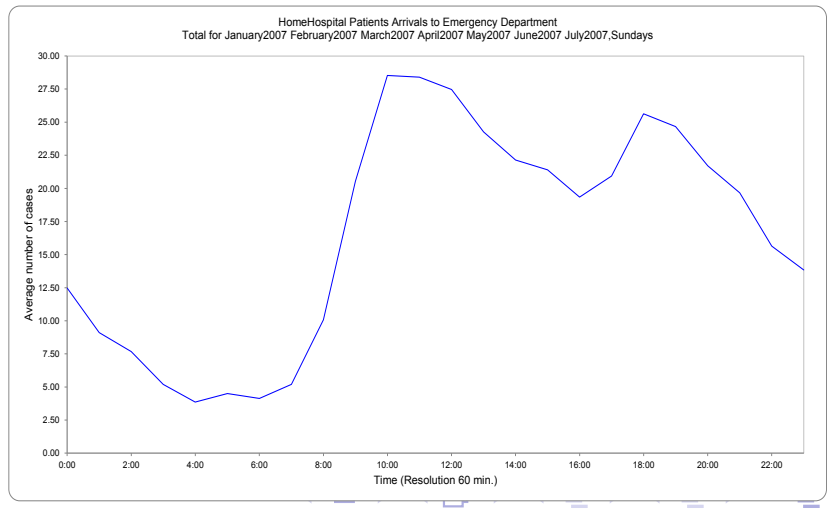
CC: May **1959** (England)



CC: Nov. 1999 (Israel)

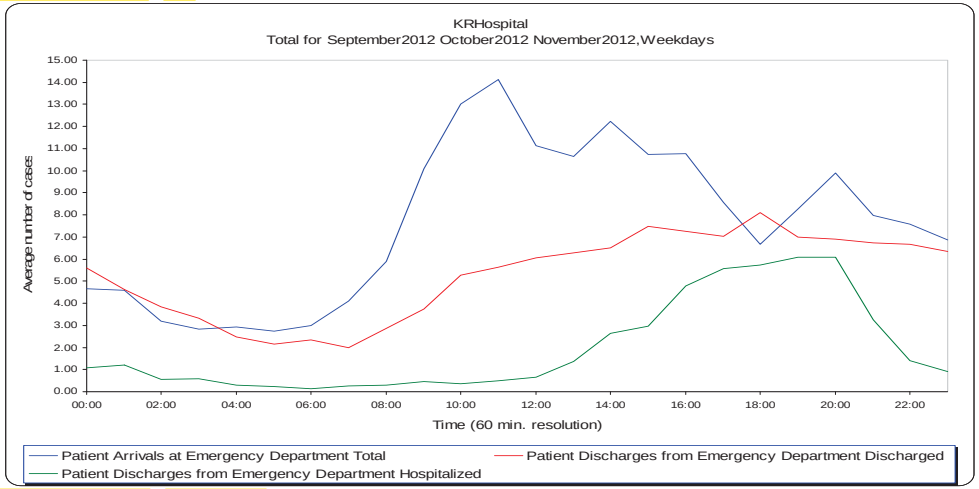


ED: Jan.–July 2007 (Israel)

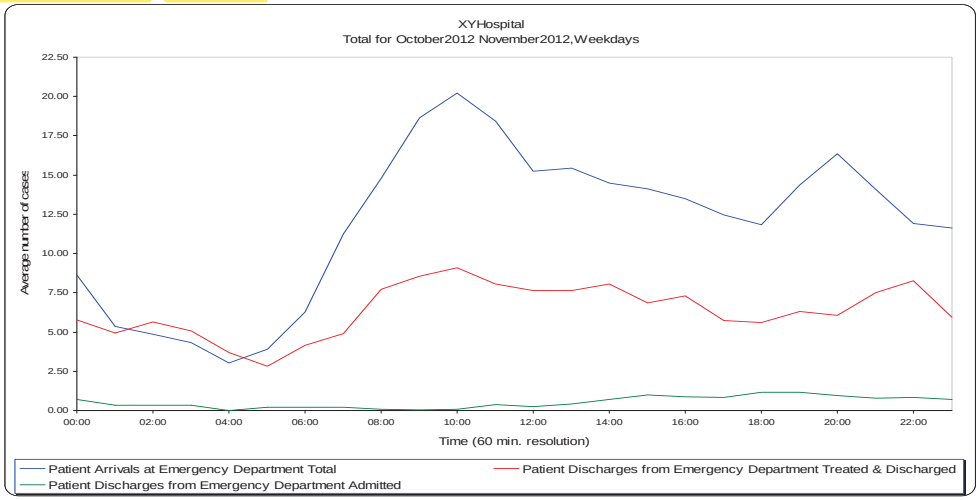


Arrival (Discharge) Rates in Korea and

KRHospital, all ED patients



XYHospital, walking patients

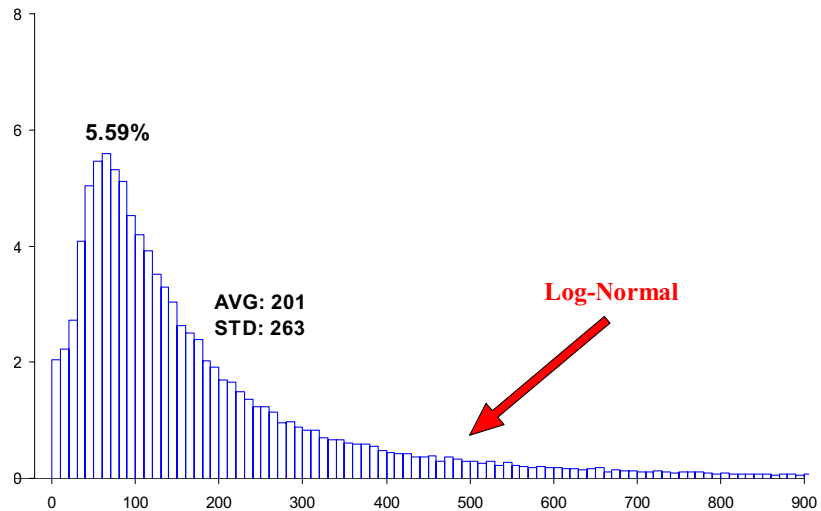


Primitives: Services (Durations)

Histogram of Service-Duration in an Israeli Call Center, 1999

Why LogNormal?

November-December

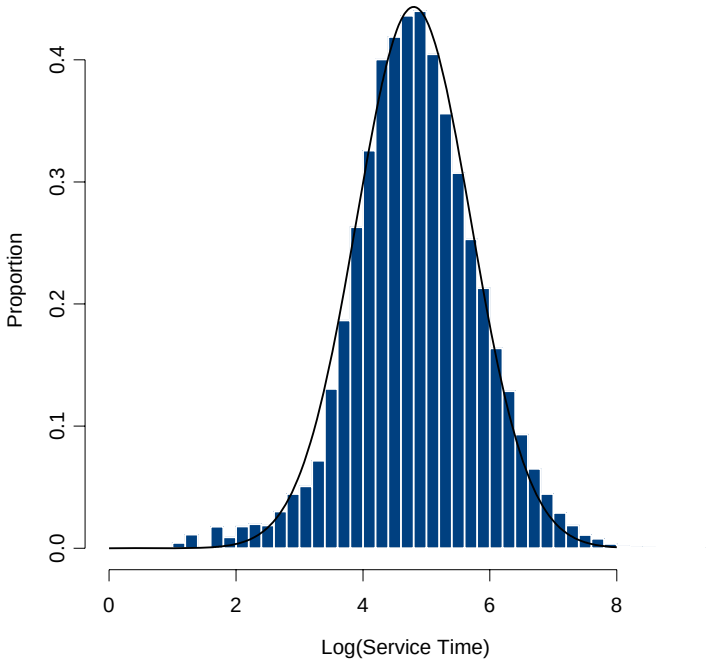


- November-December: **LogNormal** durations (common) ?

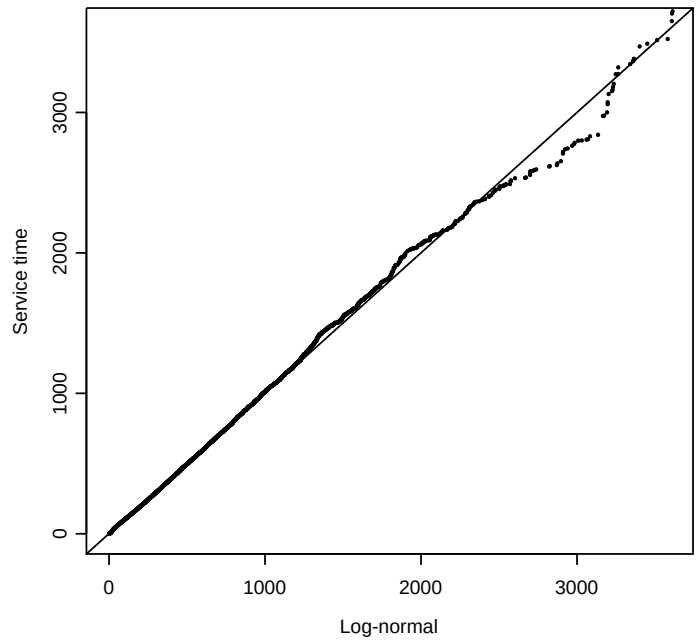
Durations: Phone Calls (2 Surprises)

Israeli Call Center, Nov–Dec, 1999

Log(Service Times)



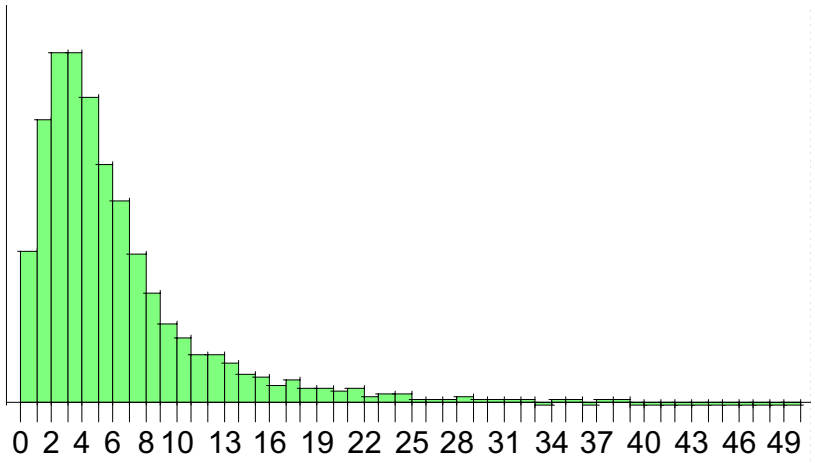
LogNormal QQPlot



- **Practically Important**: (mean, std)(log) characterization
- **Theoretically Intriguing**: Why LogNormal ? Naturally multiplicative but, in fact, also **Infinitely-Divisible** (Generalized Gamma-Convolutions)

Primitives, . . .: Length-of-Stay in a Hospital Ward

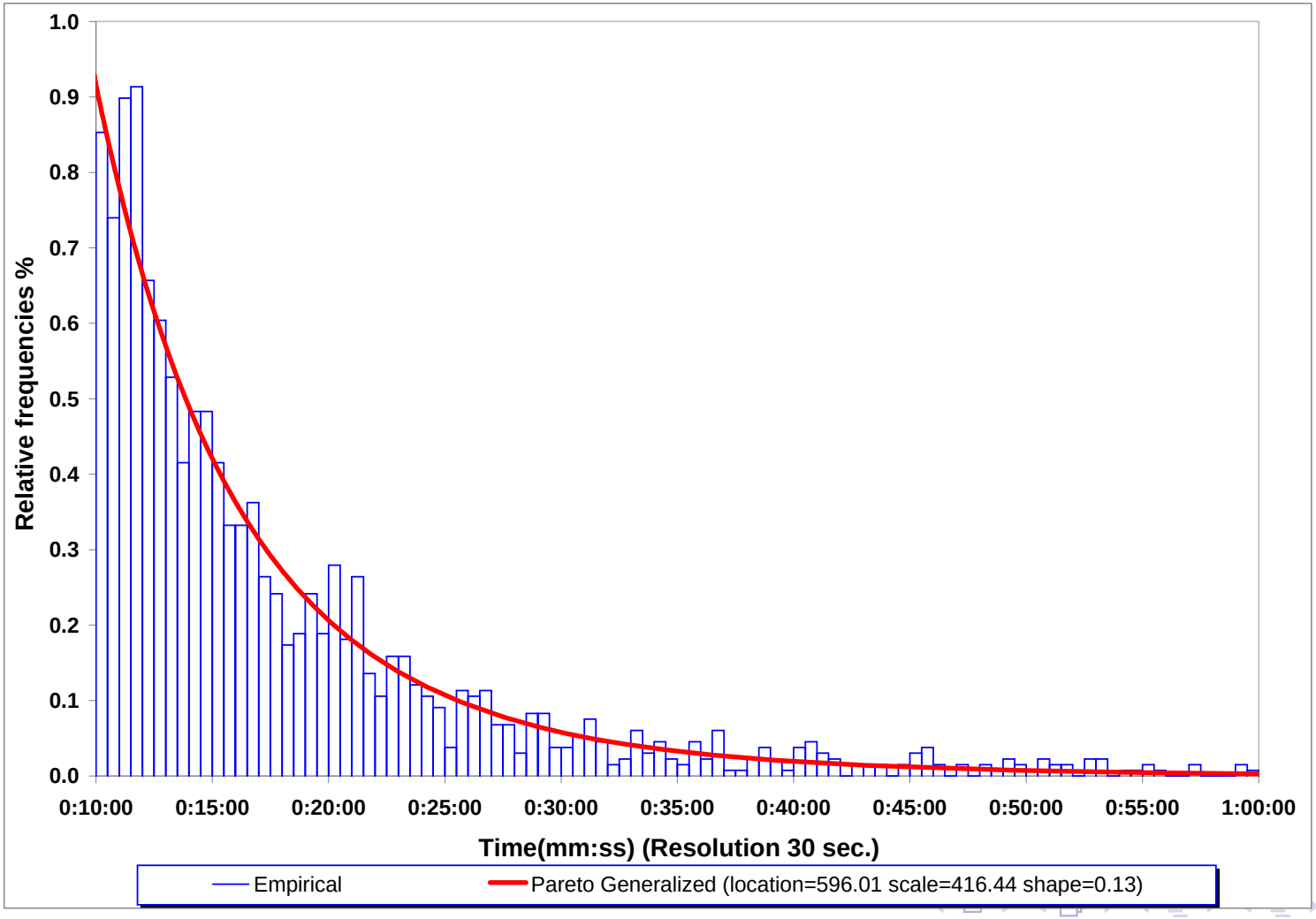
Israeli Hospital, IW LOS, in Days:



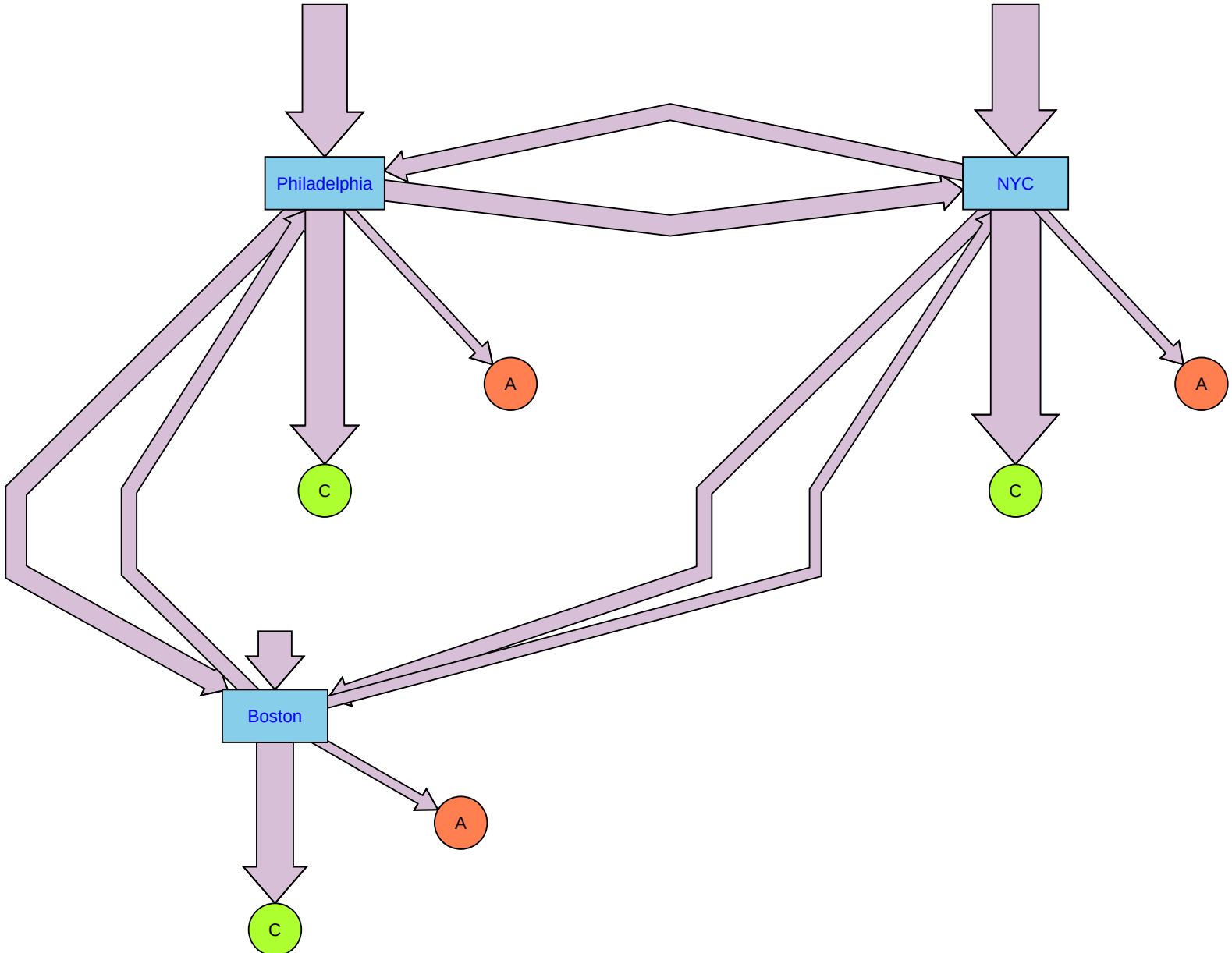
Primitives: (Im)Patience

Israeli Bank: Uncensored 13,000 Customers, 24/11/2008

Patience $\geq 10min$: Why Pareto Tail?



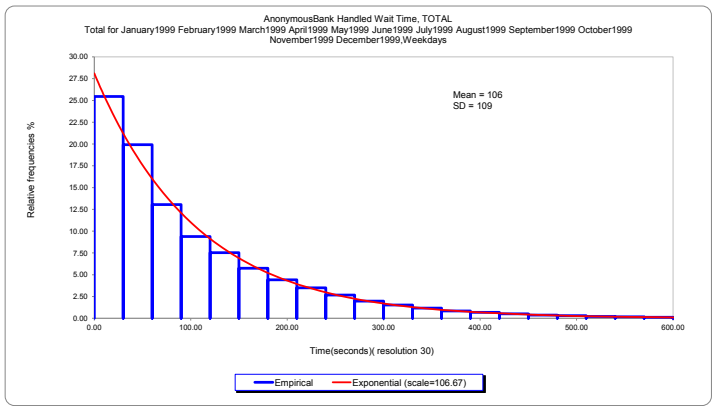
Protocol Mining: Snapshots of Connectivity



Protocols: Waiting Time in a Call Center

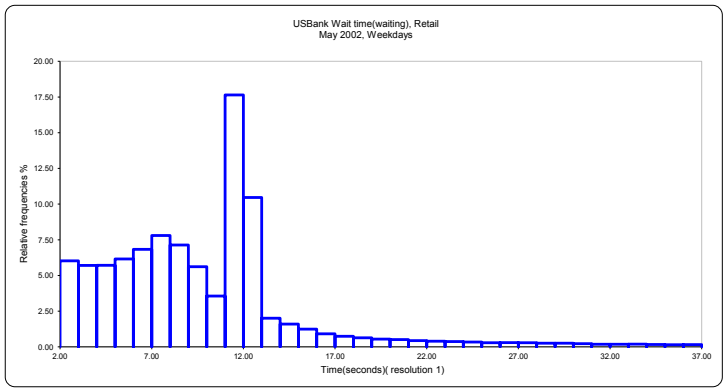
Exponential in Heavy-Traffic (min.)

Small Israeli Bank



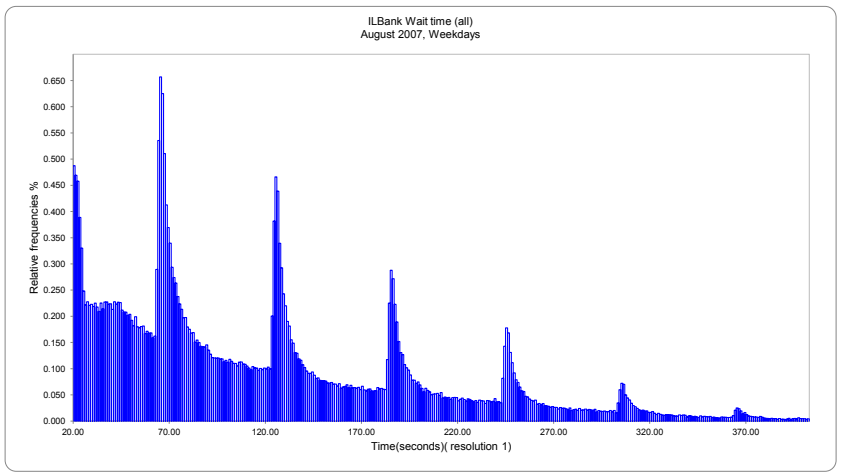
Routing via Thresholds (sec.)

Large U.S. Bank



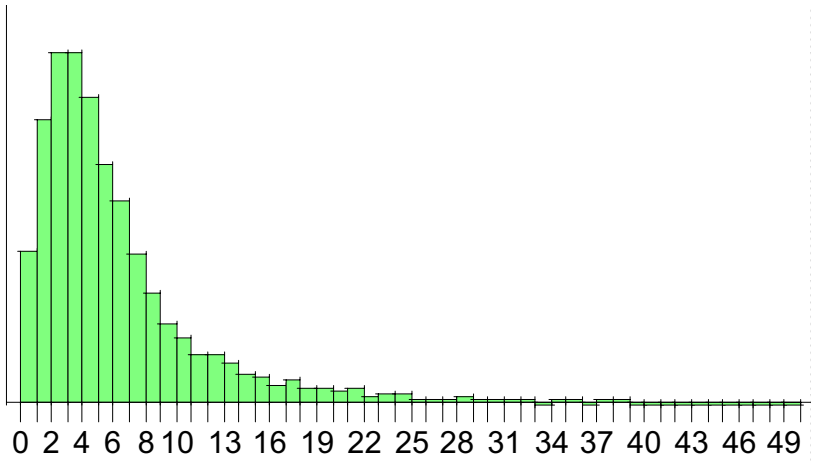
Scheduling Priorities (sec.) [compare Hospital LOS (hours)]

Medium Israeli Bank

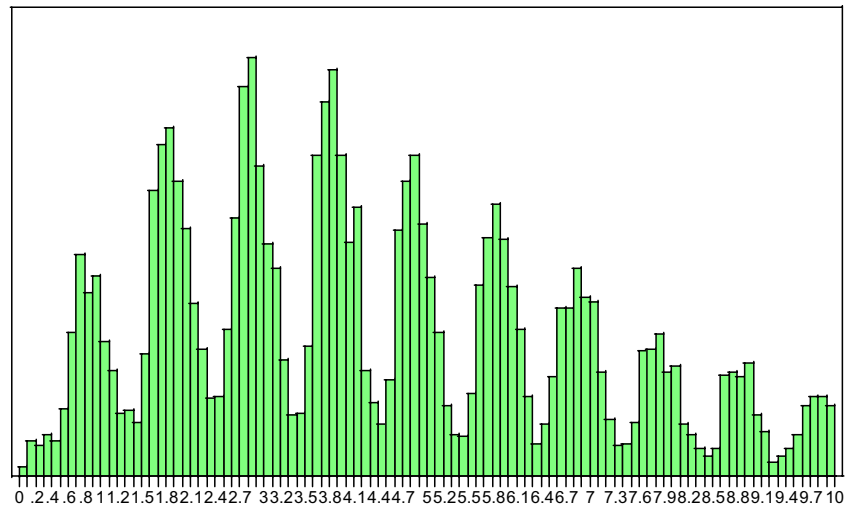


Protocols: LOS in Hospitals - Beyond LogNormal

Israeli Hospital, in Days: LN

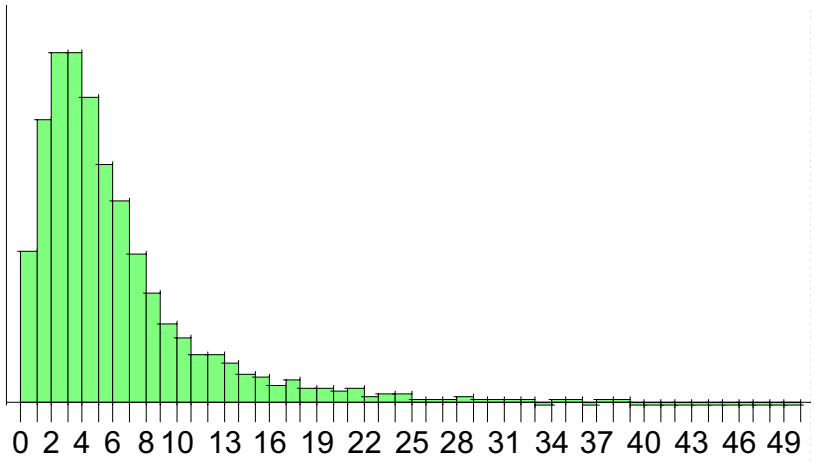


In Hours: 2 Time Scales, Mixture

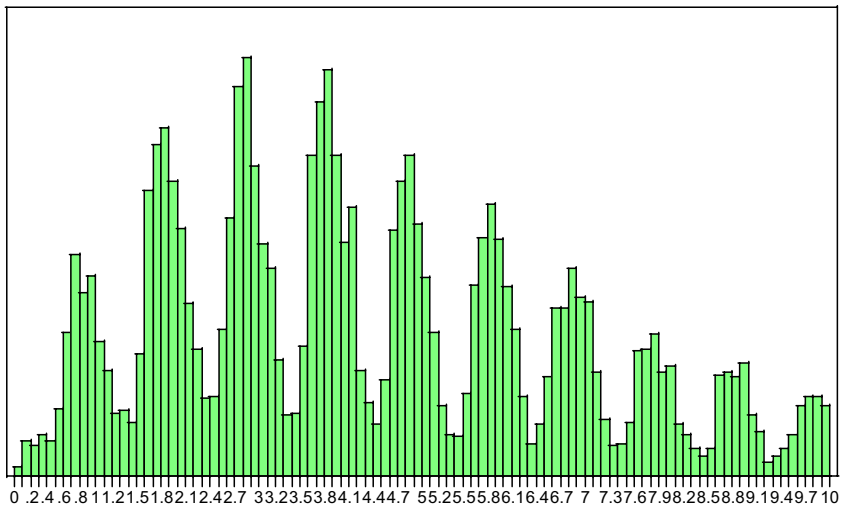


Protocols: LOS in Hospitals - Beyond LogNormal

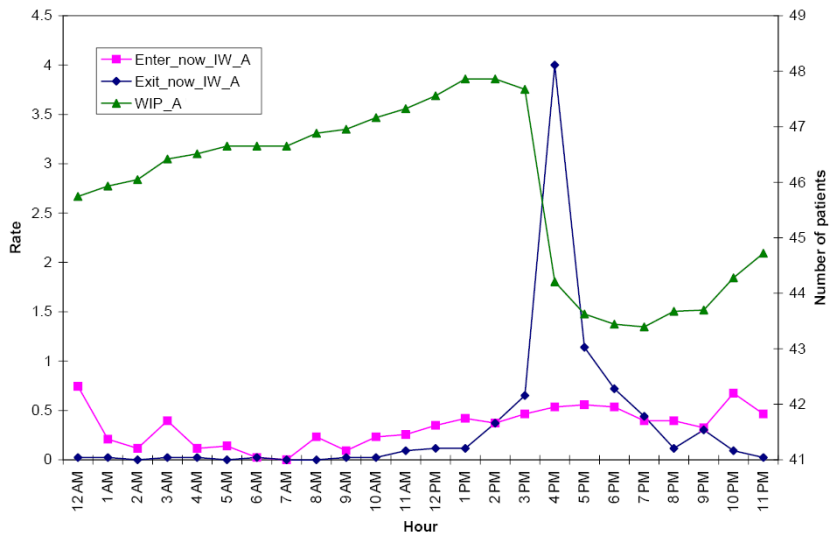
Israeli Hospital, in Days: LN



In Hours: 2 Time Scales, Mixture



Explanation: Patients released around **3pm** (2-3 in Singapore, 2-4 in UNC Hospital)



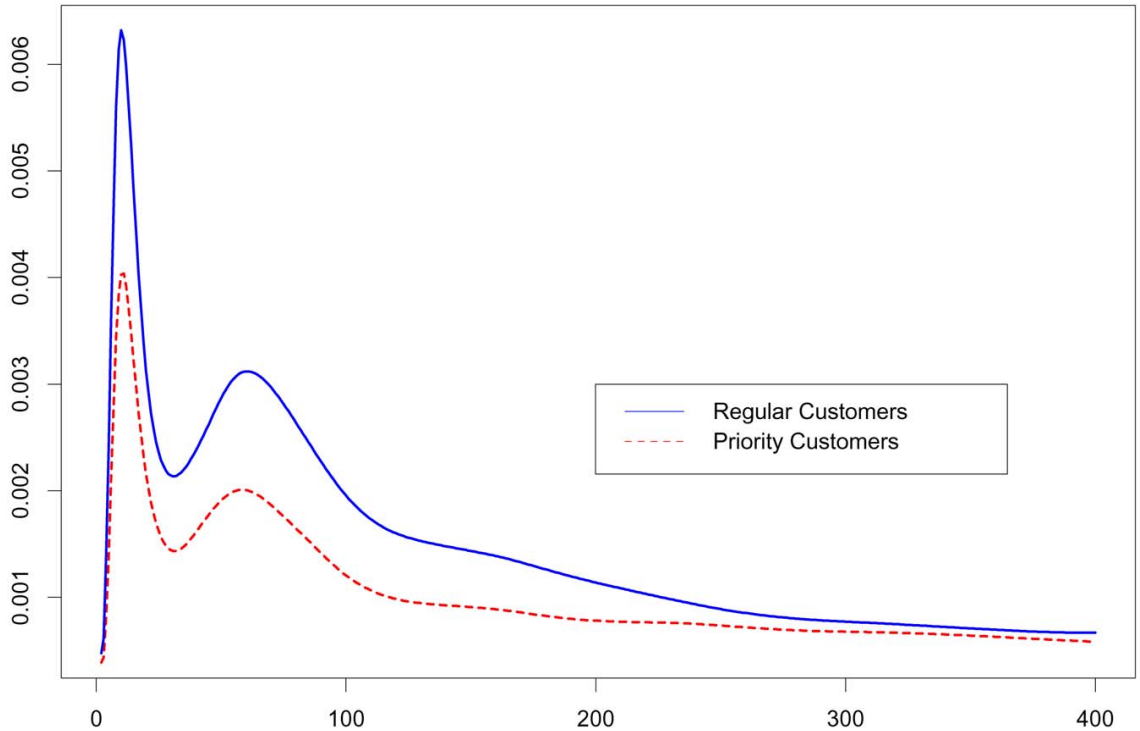
Why Bother ?

- Hourly Scale: Staffing,. . .
- Daily: Flow / Bed Control,. . .

Protocols: (Im)Patience while Waiting (Psychology)

Palm: (1943–53): **Irritation** $\propto$ **Hazard Rate**

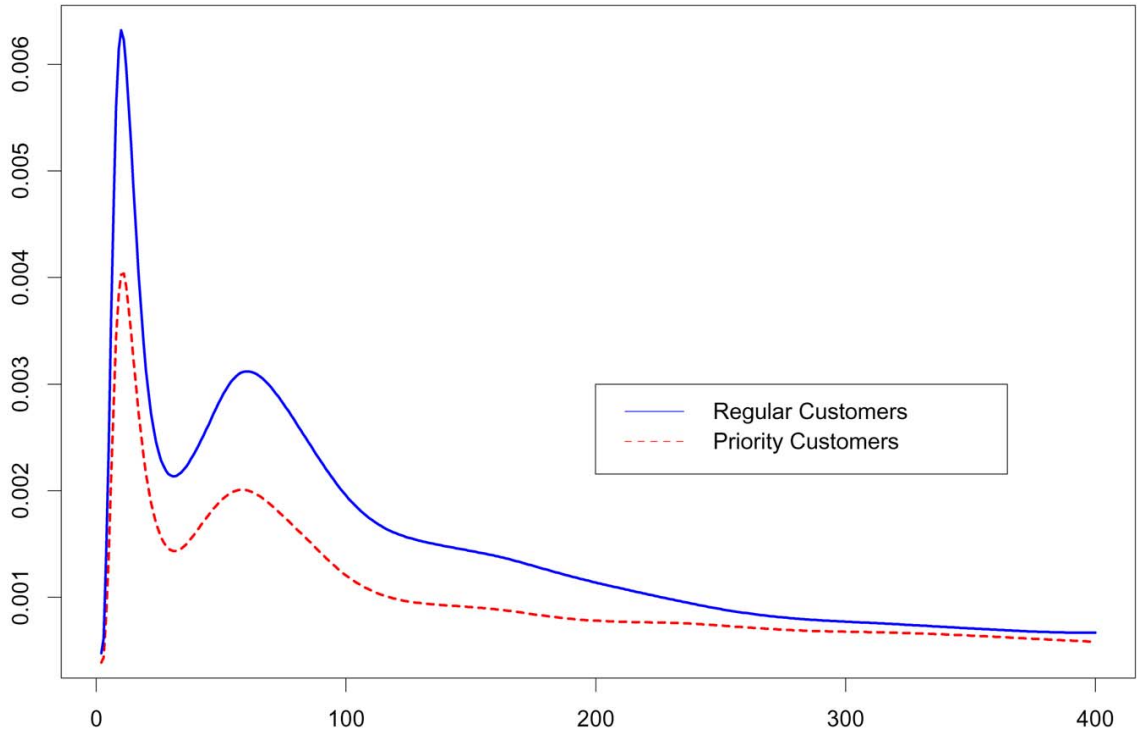
Regular over **VIP** Customers: VIP more patient here (Israeli Bank)



Protocols: (Im)Patience while Waiting (Psychology)

Palm: (1943–53): **Irritation** $\propto$ **Hazard Rate**

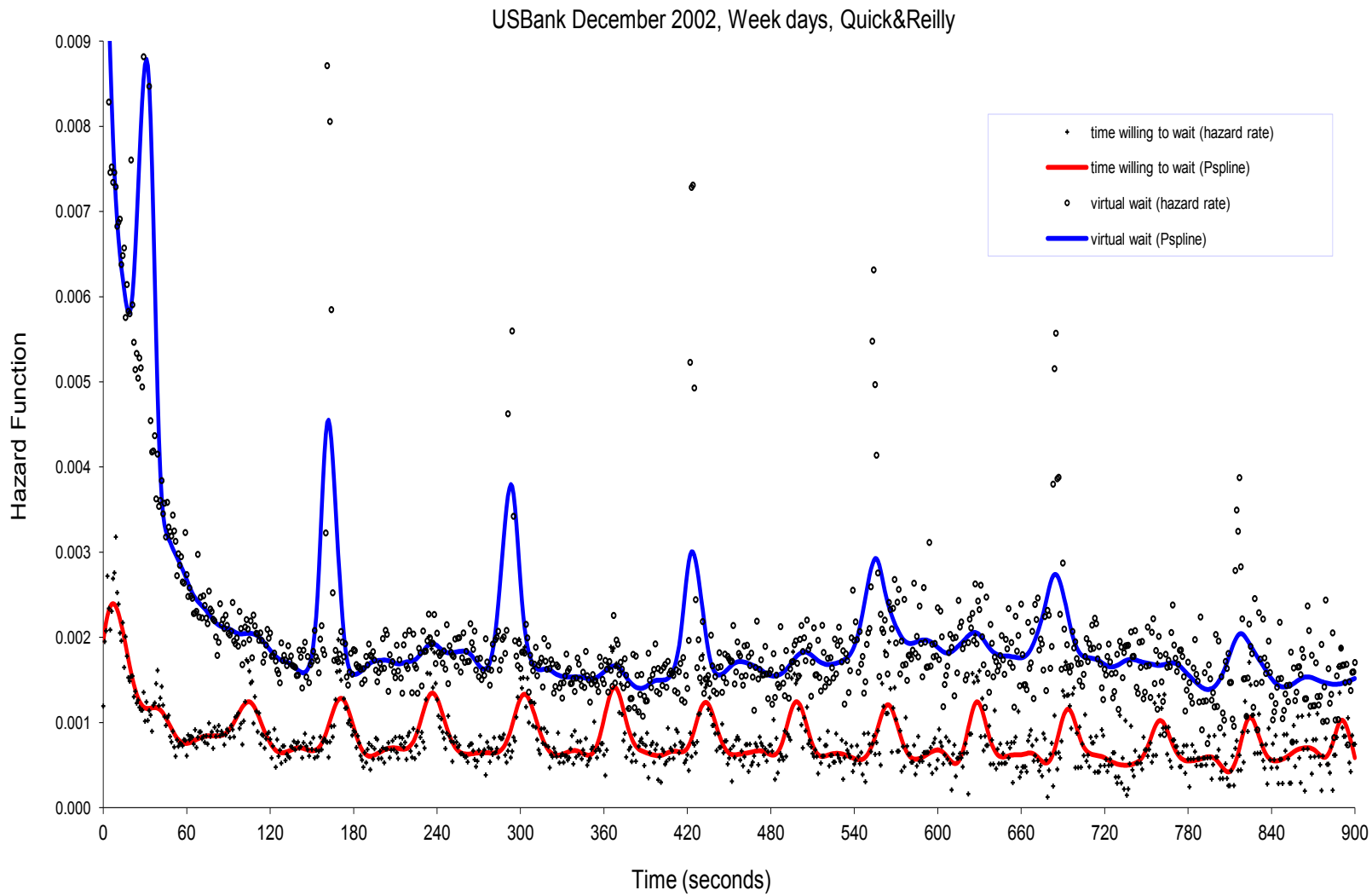
Regular over **VIP** Customers: VIP more patient here (Israeli Bank)



- Why **Peaks** of **abandonment**? **Announcement** epochs
  - Control abandonment w/ info: encourage, discourage
  - Technical Challenges, **w/ J. Huang, J. Zhang, H. Zhang**
- Statistical challenges: **Un-Censoring**, Smoothing

Protocols + Psychology

Patient Customers, Announcements, Priority Upgrades

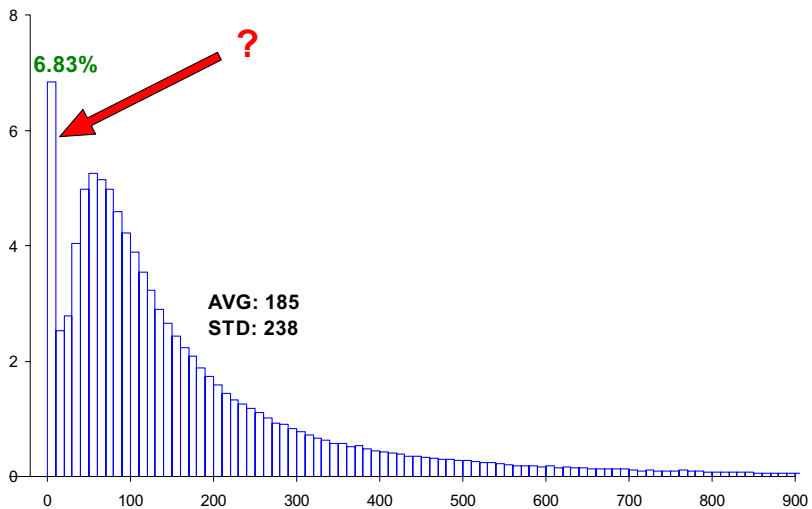


Primitives: Services (Durations)

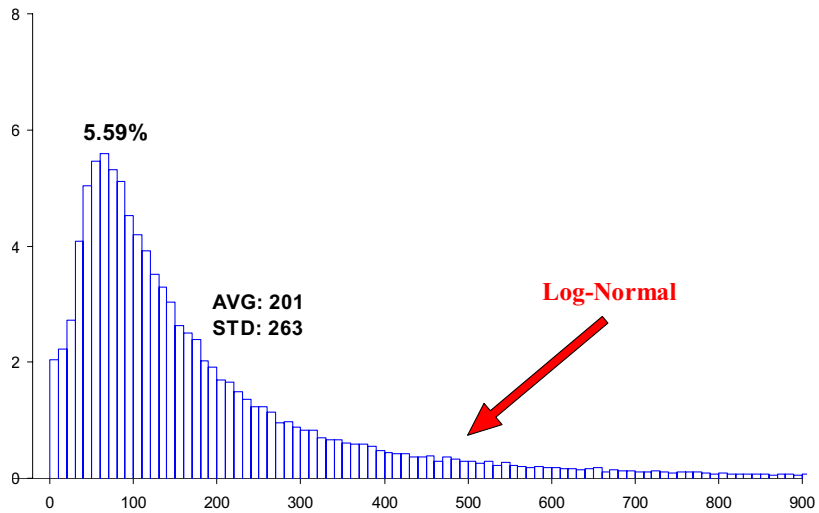
Histogram of Service-Duration in an Israeli Call Center, 1999

Why short services? Why LogNormal?

January-October



November-December



- January-October: **6.8% Short-Services** ($\leq$ 10 seconds) ?
- November-December: **LogNormal** durations (common) ?

On Data-Based Research & Teaching (Practice)

- **Operational Data** challenges: get, incomplete, corrupt; integrate with full path of care (e.g. from onset of symptoms)

On Data-Based Research & Teaching (Practice)

- **Operational Data** challenges: get, incomplete, corrupt; integrate with full path of care (e.g. from onset of symptoms)

  $\Rightarrow$ Must go beyond the prevalent paradigm (in OR/IE/OM):

  - A single researcher (with a PhD student) obtaining a small data set for a single research project

    $\Rightarrow$ Unprofessional, no learning across generations, no sharing among researchers, irreproducible research

- Ultimately, **Research Labs** will become necessary (hence must be funded!): offering universal access to data, ServNets

On Data-Based Research & Teaching (Practice)

- **Operational Data** challenges: get, incomplete, corrupt; integrate with full path of care (e.g. from onset of symptoms)

  $\Rightarrow$ Must go beyond the prevalent paradigm (in OR/IE/OM):

  - A single researcher (with a PhD student) obtaining a small data set for a single research project

    $\Rightarrow$ Unprofessional, no learning across generations, no sharing among researchers, irreproducible research

- Ultimately, **Research Labs** will become necessary (hence must be funded!): offering universal access to data, ServNets

- Data-based Research: Tradition in Physics, Chemistry, Biology; Psychology, Transportation (Science), (Behavioral) Economics

- With available data, also natural, needed and valuable in **Service Science** /Engineering/Management

On Data-Based Research & Teaching (Practice)

- **Operational Data** challenges: get, incomplete, corrupt; integrate with full path of care (e.g. from onset of symptoms)

  $\Rightarrow$ Must go beyond the prevalent paradigm (in OR/IE/OM):

  - A single researcher (with a PhD student) obtaining a small data set for a single research project

    $\Rightarrow$ Unprofessional, no learning across generations, no sharing among researchers, irreproducible research

- Ultimately, **Research Labs** will become necessary (hence must be funded!): offering universal access to data, ServNets

- Data-based Research: Tradition in Physics, Chemistry, Biology; Psychology, Transportation (Science), (Behavioral) Economics

- With available data, also natural, needed and valuable in **Service Science** /Engineering/Management

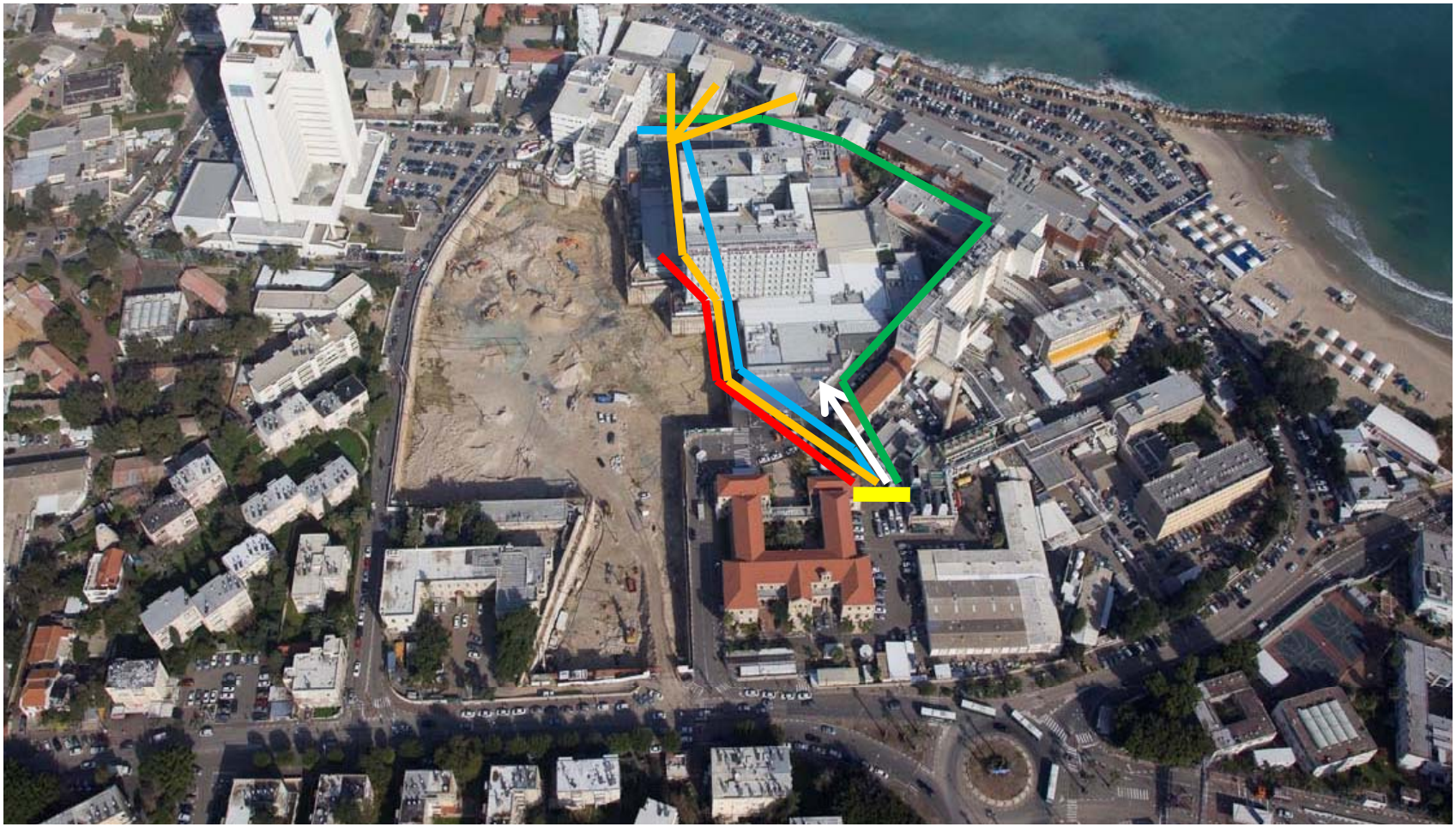
Home at Technion, IE&M, SEELab

Data-Based Creation of ServNets: some Technicalities

- **ServNets** = QNets, SimNets, FNets, DNets
- **Graph Layout**: Adapted from but significantly extends Graphviz (AT&T, 90's); eg. *edge-width*, which must be restricted to *poly-lines*, since there are "no parallel Bezier (Cubic) curves ($B_n(p) = E_p F[B(n,p)], 0 \leq p \leq 1$)
- **Algorithm**: Dot Layout (but with cycles), based on Sugiyama, Tagawa, Toda ('81): "Visual Understanding of **Hierarchical** System Structures"
- Draws data directly from **SEELab** data-bases:
  - Relational DBs (Large! eg. USBank Full Binary = 37GB, Summary Tables = 7GB)
  - Structure: Sequence of events/states, which (due to size) partitioned (yet integrated) into days (eg. call centers) or months (eg. hospitals)
  - Differs from industry DBs (in call centers, hospitals, websites)

eg. RFID-Based Data: Mass Casualty Event (MCE)

Drill: Chemical MCE, Rambam Hospital, May 2010



Focus on **severely wounded** casualties ($\approx$ 40 in drill)

Note: 20 observers support real-time control (helps validation)

Data Cleaning: MCE with RFID Support

Data-base				Company report		comment
Asset id	order	**Entry** date	**Exit** date	Entry date	Exit date	
4	1	1:14:07 PM		1:14:00 PM		
6	1	12:02:02 PM	12:33:10 PM	12:02:00 PM	12:33:00 PM	
8	1	11:37:15 AM	12:40:17 PM	11:37:00 AM		**exit is missing**
10	1	12:23:32 PM	12:38:23 PM	12:23:00 PM		
12	1	12:12:47 PM	12:35:33 PM		12:35:00 PM	**entry is missing**
15	1	1:07:15 PM		1:07:00 PM		
16	1	11:18:19 AM	11:31:04 AM	11:18:00 AM	11:31:00 AM	
17	1	1:03:31 PM		1:03:00 PM		
18	1	1:07:54 PM		1:07:00 PM		
19	1	12:01:58 PM		12:01:00 PM		
20	1	11:37:21 AM	12:57:02 PM	11:37:00 AM	12:57:00 PM	
21	1	12:01:16 PM	12:37:16 PM	12:01:00 PM		
22	1	12:04:31 PM	12:20:40 PM			first customer is missing
22	2	12:27:37 PM		12:27:00 PM		
25	1	12:27:35 PM	1:07:28 PM	12:27:00 PM	1:07:00 PM	
27	1	12:06:53 PM		12:06:00 PM		
28	1	11:21:34 AM	11:41:06 AM	11:41:00 AM	11:53:00 AM	**exit time instead of entry time**
29	1	12:21:06 PM	12:54:29 PM	12:21:00 PM	12:54:00 PM	
31	1	11:40:54 AM	12:30:16 PM	11:40:00 AM	12:30:00 PM	
31	2	12:37:57 PM	12:54:51 PM	12:37:00 PM	12:54:00 PM	
32	1	11:27:11 AM	12:15:17 PM	11:27:00 AM	12:15:00 PM	
33	1	12:05:50 PM	12:13:12 PM	12:05:00 PM	12:15:00 PM	wrong exit time
35	1	11:31:48 AM	11:40:50 AM	11:31:00 AM	11:40:00 AM	
36	1	12:06:23 PM	12:29:30 PM	12:06:00 PM	12:29:00 PM	
37	1	11:31:50 AM	11:48:18 AM	11:31:00 AM	11:48:00 AM	
37	2	12:59:21 PM		12:59:00 PM		

- Imagine **“Cleaning" 60,000+ customers per day** (call centers) !
- “Psychology" of Data Trust and Transfer (e.g. 2 years till transfer)

Event-Logs in a Call Center (Bank Anonymous)

A Data Sample (Excel worksheet)

vru+line	call_id	customer_id	priority	type	date	vru_entry	vru_exit	vru_time	q_start	q_exit	q_time	outcome	ser_start	ser_exit	ser_time	server
AA0101	44749	27644400	2	PS	990901	11:45:33	11:45:39	6	11:45:39	11:46:58	79	AGENT	11:46:57	11:51:00	243	DORIT
AA0101	44750	12887816	1	PS	990905	14:49:00	14:49:06	6	14:49:06	14:53:00	234	AGENT	14:52:59	14:54:29	90	ROTH
AA0101	44967	58660291	2	PS	990905	14:58:42	14:58:48	6	14:58:48	15:02:31	223	AGENT	15:02:31	15:04:10	99	ROTH
AA0101	44968	0	0	NW	990905	15:10:17	15:10:26	9	15:10:26	15:13:19	173	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44969	63193346	2	PS	990905	15:22:07	15:22:13	6	15:22:13	15:23:21	68	AGENT	15:23:20	15:25:25	125	STEREN
AA0101	44970	0	0	NW	990905	15:31:33	15:31:47	14	00:00:00	00:00:00	0	AGENT	15:31:45	15:34:16	151	STEREN
AA0101	44971	41630443	2	PS	990905	15:37:29	15:37:34	5	15:37:34	15:38:20	46	AGENT	15:38:18	15:40:56	158	TOVA
AA0101	44972	64185333	2	PS	990905	15:44:32	15:44:37	5	15:44:37	15:47:57	200	AGENT	15:47:56	15:49:02	66	TOVA
AA0101	44973	3.06E+08	1	PS	990905	15:53:05	15:53:11	6	15:53:11	15:56:39	208	AGENT	15:56:38	15:56:47	9	MORIAH
AA0101	44974	74780917	2	NE	990905	15:59:34	15:59:40	6	15:59:40	16:02:33	173	AGENT	16:02:33	16:26:04	1411	ELI
AA0101	44975	55920755	2	PS	990905	16:07:46	16:07:51	5	16:07:51	16:08:01	10	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44976	0	0	NW	990905	16:11:38	16:11:48	10	16:11:48	16:11:50	2	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44977	33689787	2	PS	990905	16:14:27	16:14:33	6	16:14:33	16:14:54	21	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44978	23817067	2	PS	990905	16:19:11	16:19:17	6	16:19:17	16:19:39	22	AGENT	16:19:38	16:21:57	139	TOVA
AA0101	44764	0	0	PS	990901	15:03:26	15:03:36	10	00:00:00	00:00:00	0	AGENT	15:03:35	15:06:36	181	ZOHARI
AA0101	44765	25219700	2	PS	990901	15:14:46	15:14:51	5	15:14:51	15:15:10	19	AGENT	15:15:09	15:17:00	111	SHARON
AA0101	44766	0	0	PS	990901	15:25:48	15:26:00	12	00:00:00	00:00:00	0	AGENT	15:25:59	15:28:15	136	ANAT
AA0101	44767	58859752	2	PS	990901	15:34:57	15:35:03	6	15:35:03	15:35:14	11	AGENT	15:35:13	15:35:15	2	MORIAH
AA0101	44768	0	0	PS	990901	15:46:30	15:46:39	9	00:00:00	00:00:00	0	AGENT	15:46:38	15:51:51	313	ANAT
AA0101	44769	78191137	2	PS	990901	15:56:03	15:56:09	6	15:56:09	15:56:28	19	AGENT	15:56:28	15:59:02	154	MORIAH
AA0101	44770	0	0	PS	990901	16:14:31	16:14:46	15	00:00:00	00:00:00	0	AGENT	16:14:44	16:16:02	78	BENSION
AA0101	44771	0	0	PS	990901	16:38:59	16:39:12	13	00:00:00	00:00:00	0	AGENT	16:39:11	16:43:35	264	VICKY
AA0101	44772	0	0	PS	990901	16:51:40	16:51:50	10	00:00:00	00:00:00	0	AGENT	16:51:49	16:53:52	123	ANAT
AA0101	44773	0	0	PS	990901	17:02:19	17:02:28	9	00:00:00	00:00:00	0	AGENT	17:02:28	17:07:42	314	VICKY
AA0101	44774	32387482	1	PS	990901	17:18:18	17:18:24	6	17:18:24	17:19:01	37	AGENT	17:19:00	17:19:35	35	VICKY
AA0101	44775	0	0	PS	990901	17:38:53	17:39:05	12	00:00:00	00:00:00	0	AGENT	17:39:04	17:40:43	99	TOVA

- Unsynchronized transition times, consistently

Prevalent (Asymptotic) Approximations

System (Data)

Model

SimNet **Q-Net**

Prevalent (Asymptotic) Approximations

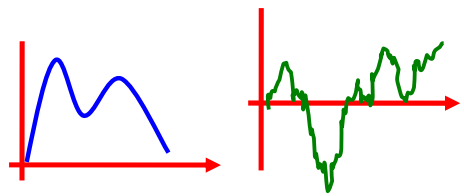
System (Data)

Phenomenon

Accuracy

Model ⟷ **Approximation**

SimNet **Q-Net** **F-Net** **D-Net**



Data–Based Prevalent (Asymptotic) Approximations Models

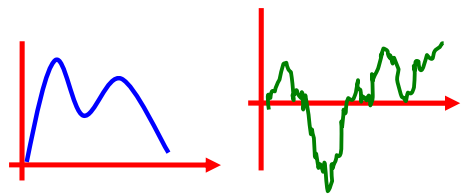
System (Data)

Phenomenon

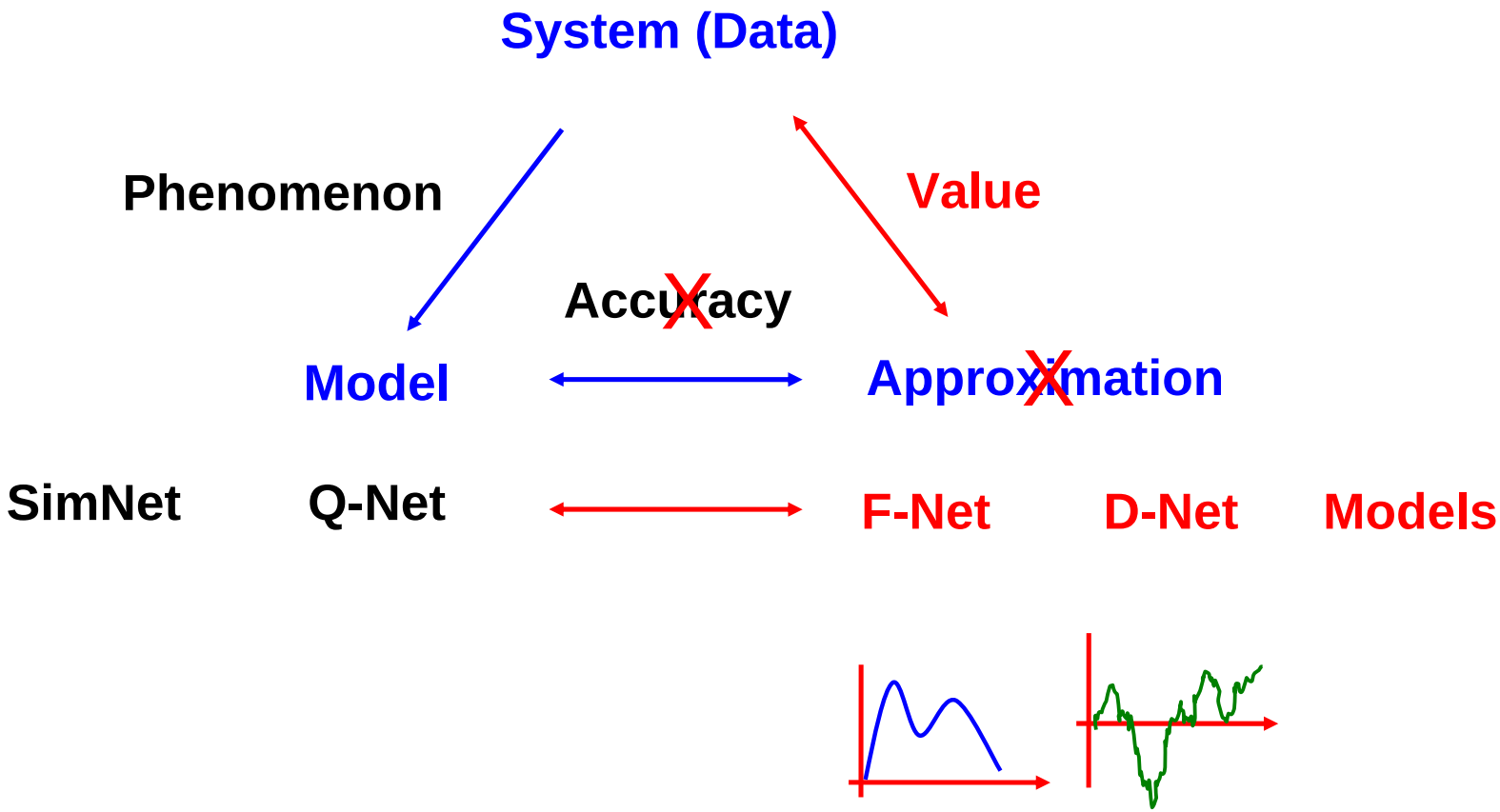
Accuracy

Model ⟷ Approximation

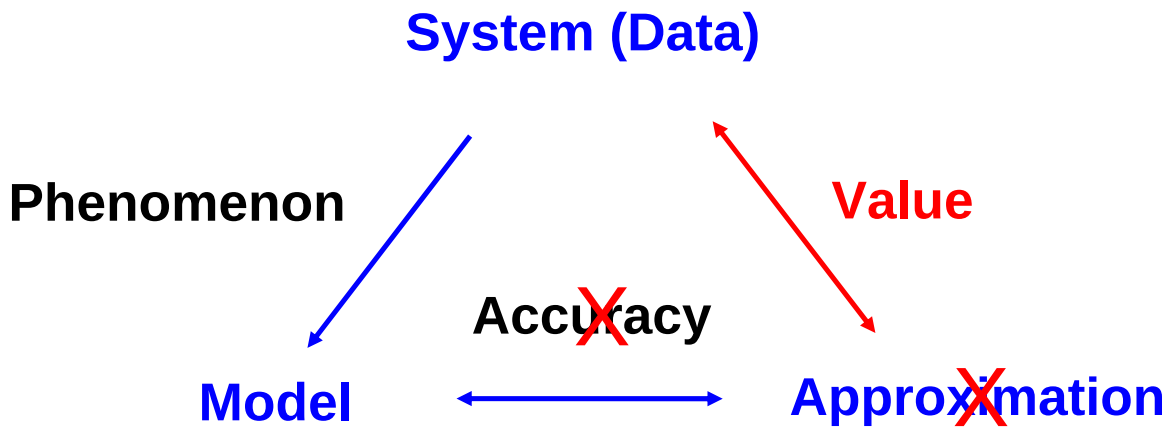
SimNet Q-Net ⟷ F-Net D-Net Models



Data–Based Prevalent (Asymptotic) Approximations Models



Data–Based Prevalent (Asymptotic) Approximations Models



System = Coin Tossing, **Model** = Binomial ; de Moivre 1738

Approx. / Models: SLLN **(FNets)**, CLT **(DNets)** ; Laplace 1810

Value: Exceeds Value of originating stylized model

Normal, Brownian Motion ; Bachalier 1900

Poisson ; Poisson 1838