Algorithmic Decision Theory and the Port Reopening Scheduling Problem

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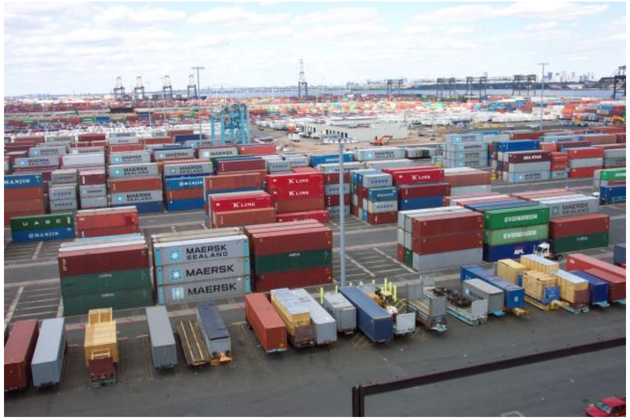
Vulnerability of Ports

- Considerable effort to introduce data-science-based methods to make our ports safer.
- Other CCICADA efforts on container inspection are part of that.
- Those efforts concentrate on inspection of cargo.
- The project I will describe is concerned with ways in which ports might be shut down in part or entirely and then reopened.



Vulnerability of Ports

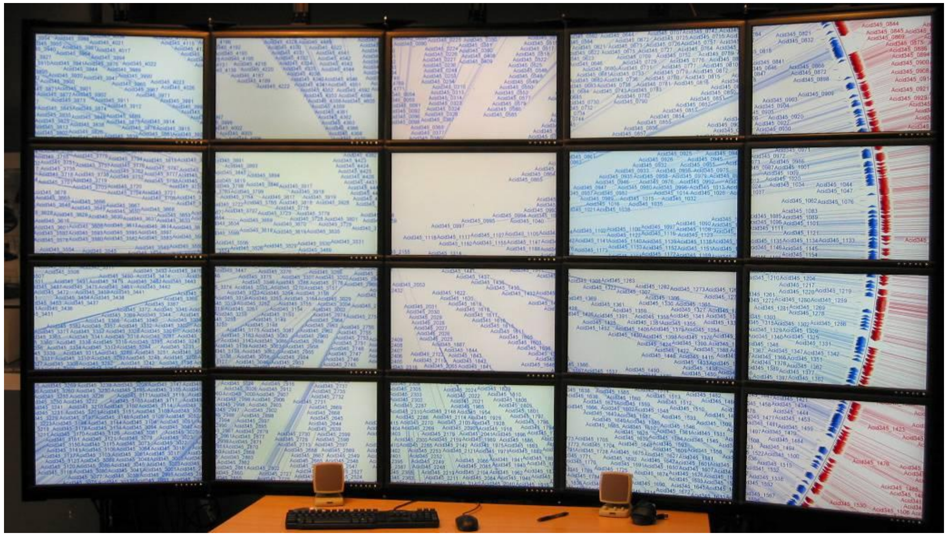
- Ports might be shut down by terrorist attacks, natural disasters like hurricanes or ice storms, strikes or other domestic disputes, etc.
- Project themes:
  - ***How do we design port operations to minimize vulnerability to shut down?***
  - ***How do we reschedule port operations in case of a shutdown?***

Algorithmic Decision Theory

- This project is related to a larger thrust on "algorithmic decision theory"
- Today's decision makers in fields ranging from engineering to medicine to homeland security have available to them:
  - Remarkable new technologies
  - Huge amounts of information
  - Ability to share information at unprecedented speeds and quantities

Algorithmic Decision Theory

- **These tools and resources will enable better decisions if we can surmount concomitant challenges:**
  - –The massive amounts of data available are often incomplete or unreliable or distributed and there is great uncertainty in them



Algorithmic Decision Theory

- **These tools and resources will enable better decisions if we can surmount concomitant challenges:**
  - –Interoperating/distributed decision makers and decision-making devices need to be coordinated
  - –Many sources of data need to be fused into a good decision, often in a remarkably short time

Algorithmic Decision Theory

- **These tools and resources will enable better decisions if we can surmount concomitant challenges:**
  - Decisions must be made in dynamic environments based on partial information
  - There is heightened risk due to extreme consequences of poor decisions
  - Decision makers must understand complex, multi-disciplinary problems

Algorithmic Decision Theory

- In the face of these new opportunities and challenges, ADT aims to exploit algorithmic methods to improve the performance of decision makers (human or automated).
- Long tradition of algorithmic methods in logistics and planning dating at least to World War II.
- But: algorithms to speed up and improve real-time decision making are much less common

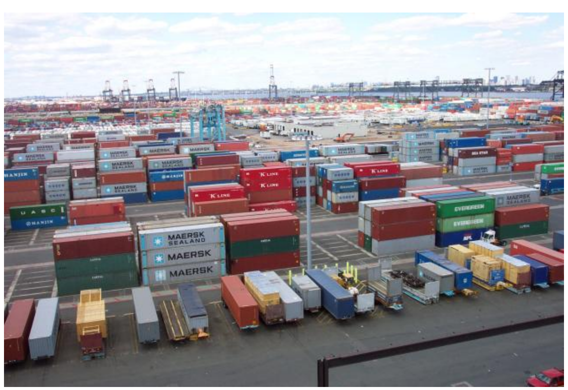
Photo # 80-G-19930 Rescuing survivor near USS West Virginia, during Pearl Harbor raid

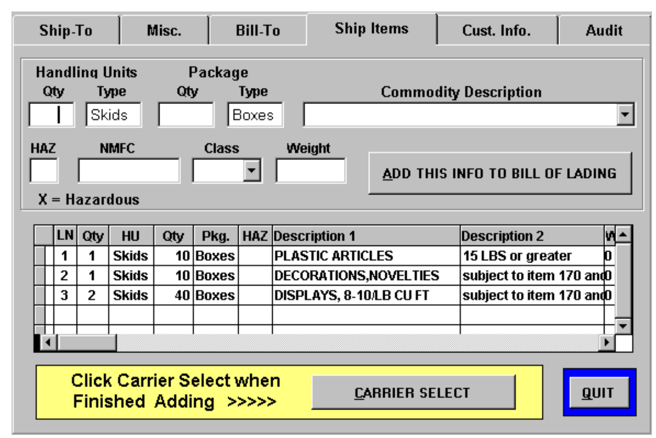
Reopening a Port After Shutdown

- Shutting down ports is not unusual – e.g., hurricanes
- Scheduling and prioritizing in reopening the port is often done very informally
- Improving on existing decision support tools for port reopening could allow us to take many more considerations into effect
- Can modern algorithmic methods of ADT help here?

Manifest Data

- Part of the solution to the port reopening problem: Detailed information about incoming cargo:
  - What is it?
  - What is its final destination?
  - What is the economic impact of delayed delivery?
- A key is to use container ***manifest data*** to estimate economic impact of various disaster scenarios & understand our port reopening requirements





Data Description

- We obtained from CBP one month's data of all cargo shipments to all US ports
- Jan 30, 2009 – Feb 28, 2009
- Description
  - Foreign port (origin)
  - Domestic port (destination)
    - Aggregation
  - Item description
  - Item count
    - Inconsistencies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1APLUUSPRES ADAMS          0018646010612O2APLU054491153   53313000000001000PKGS 00000020230KG00000000026CMDLUDHIANA, IN          861693400100000040PORW
1APZU3102448   APL251813                   G0020000000080600000080022G0LCY
3AGRO DUTCH INDUSTRIES LIMITED      C/O ABBY FOODS LLC,               1900 THE EXCHANGE SUITE 385,       ATLANTA,GA 30339,USA
4INTERNATIONAL TRADE LOGISTICS,     2525 BRUNSWICK AVENUE,SUITE 200,   LINDEN,NJ 07036,USA
5APZU3102448   00000010006/62 OZ 1000 PACKAGES                              000000000000000000 0000000000CANNED MUSHROOMS
5APZU3102448   0000000000TEN KNOCKDOWN EMPTY CARTONS                        000000000000000000 0000000000INV.NO:ADIL/1121 DT.06/11/2006
5APZU3102448   0000000000PO.NO:A5608093                                     000000000000000000 0000000000U.S.FDA REGISTRATION NUMBER:
5APZU3102448   0000000000NET.WT.19842.000 KGS                               000000000000000000
7APZU3102448   1689173                         TO                                               1690172                          ;
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Data Description

- Data has errors and ambiguities
- Does 150 waters mean 150 bottles of water or 150 cases of bottles of water?
- What does "household goods" mean?

- Still, there are things we can do with the data.

Mining of Manifest Data

- Separate effort: Predict risk score for each container
  - Quantify the likelihood of need for inspection
  - Based on covariates/characteristics of a container's manifest data.
- Methods:
  - We are developing machine learning algorithms to detect anomalies in manifest data.
  - Text mining on verbiage fields.
  - Logistic regression with LASSO.
    - Simulation study conducted suggests that the LASSO regression approach is an effective tool for processing information in the manifest data

Visualization Tools Applied to Manifest Data

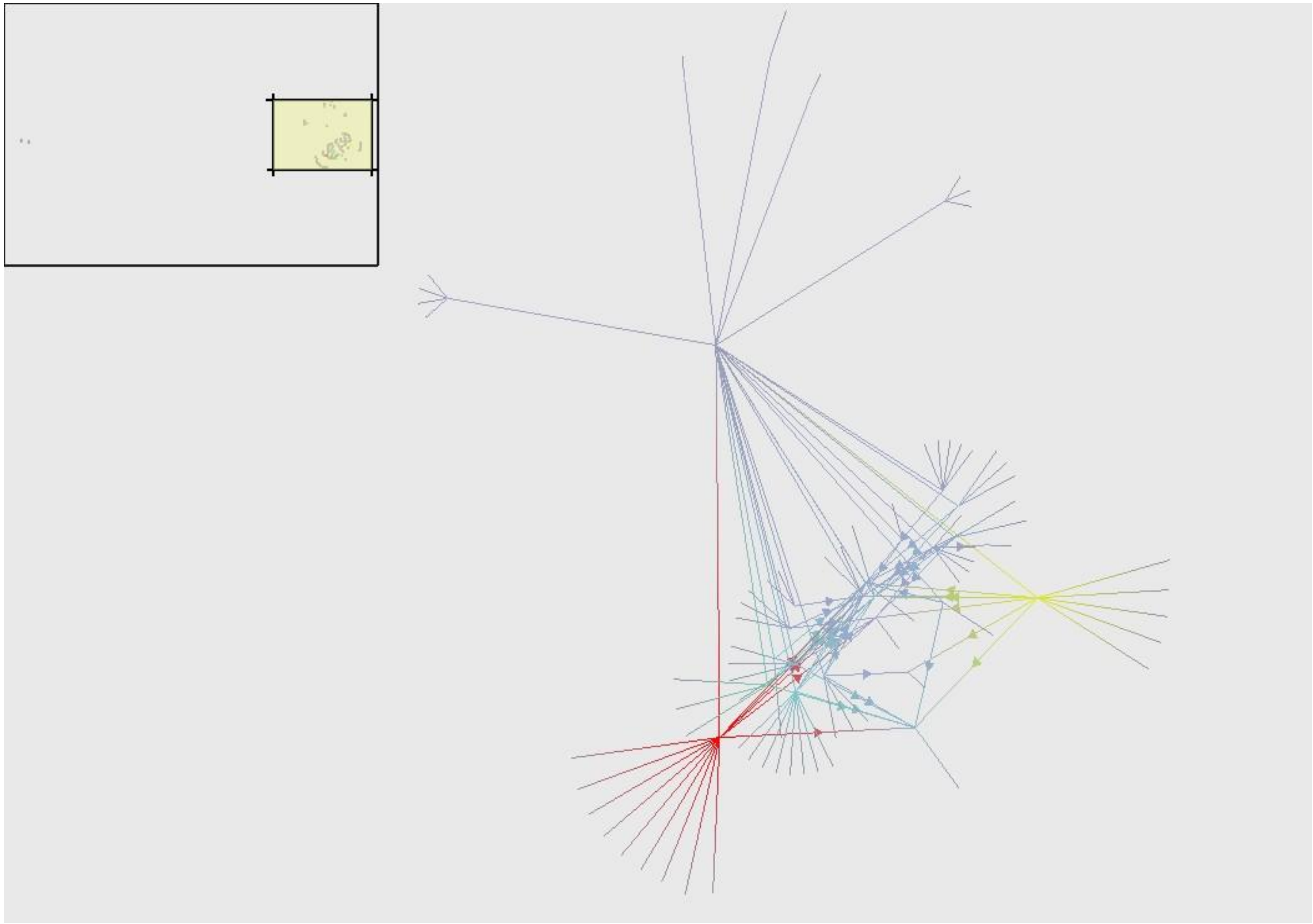
- Visualizing data can give us insight into interconnections, patterns, and what is "normal" or "abnormal."
- Visualization is part of another effort, but similar methods can help with the port reopening problem
- Our visual analysis methods are based on tools originally developed at AT&T for detection of anomalies in telephone calling patterns – e.g., quick detection that someone has stolen your AT&T calling card.
- The visualizations are interactive so you can "zoom" in on areas of interest, get different ways to present the data, etc.
- Work of James Abello and Tsvetan Asamov

Visualization Tools for Risk Assessment/Anomaly Detection

- For port p, a vector *contents[p]* gives the number of items of each kind of commodity shipped out of port p in a given time period.
- We devise ***similarity measures*** between ports p and q as a function of the dot product of their contents vectors.
- *Contents[p,q]* gives the number of items of each kind of commodity shipped from port p to port q in a given time period.
- We represent such vectors using edge-weighted, labeled graphs that can be visualized using our software.

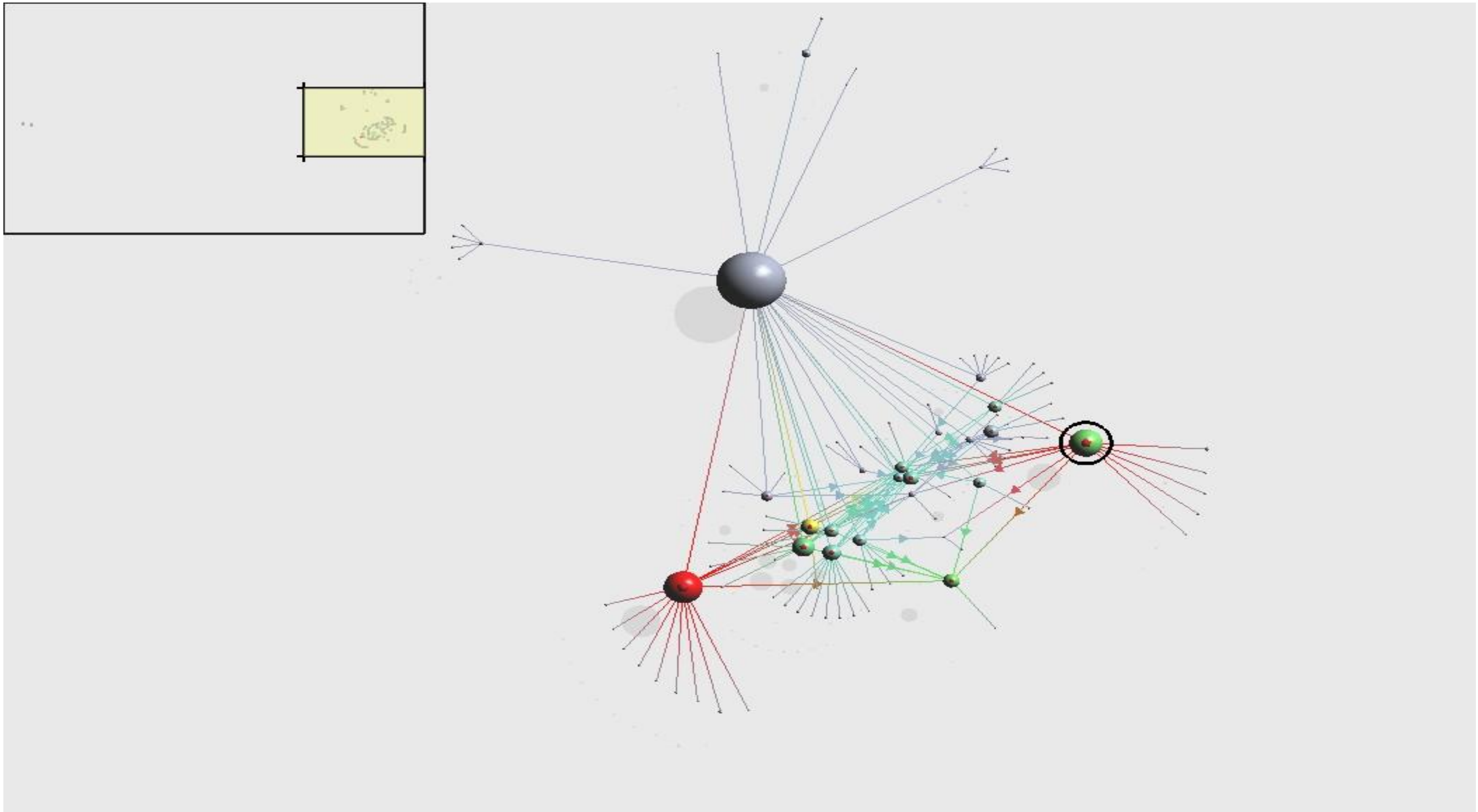
General View of Port to Port Traffic

Color-coded connections represent number of shipments



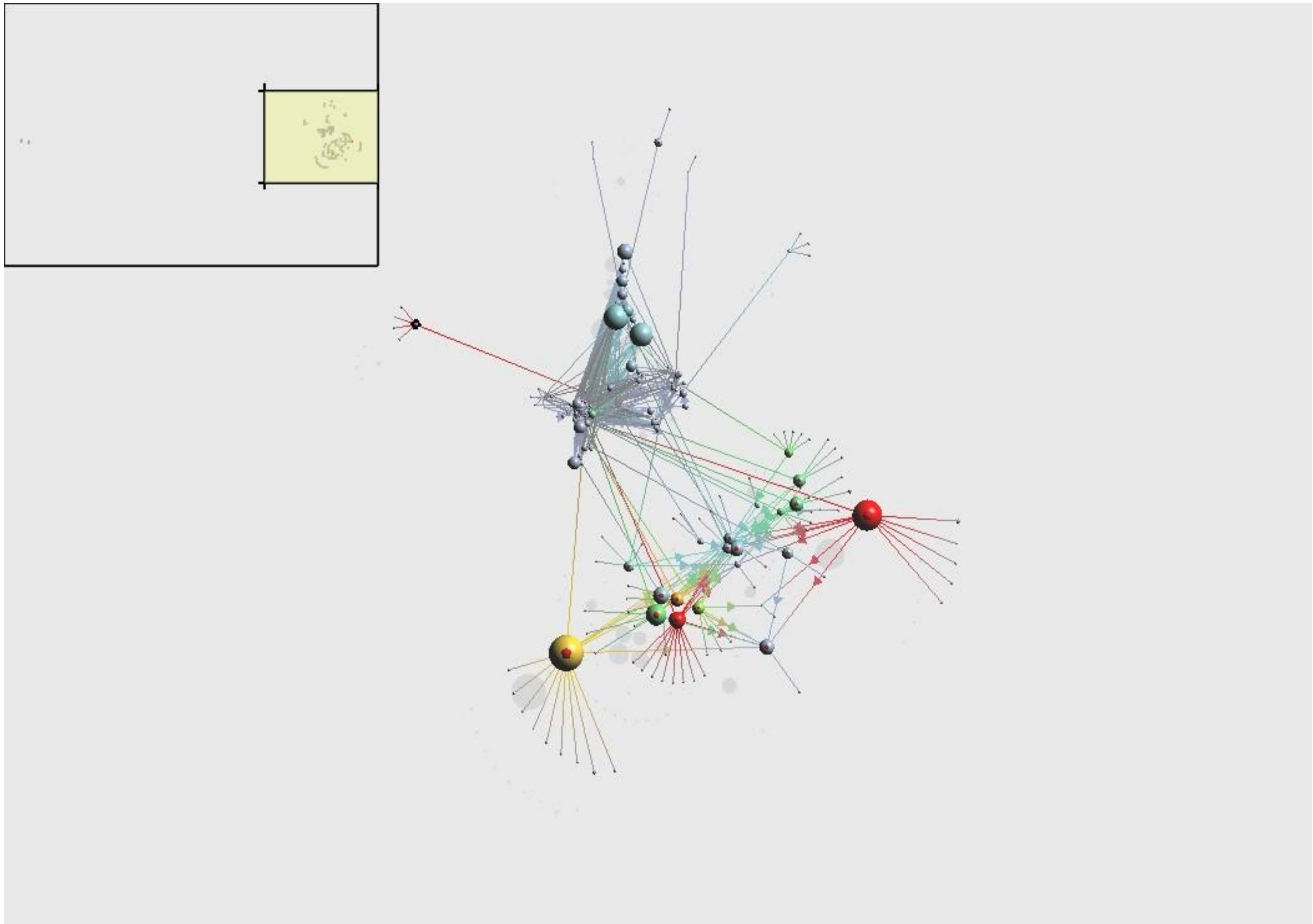
Shanghai, LA, Newark, Singapore

Vertex Size encodes number of shipments



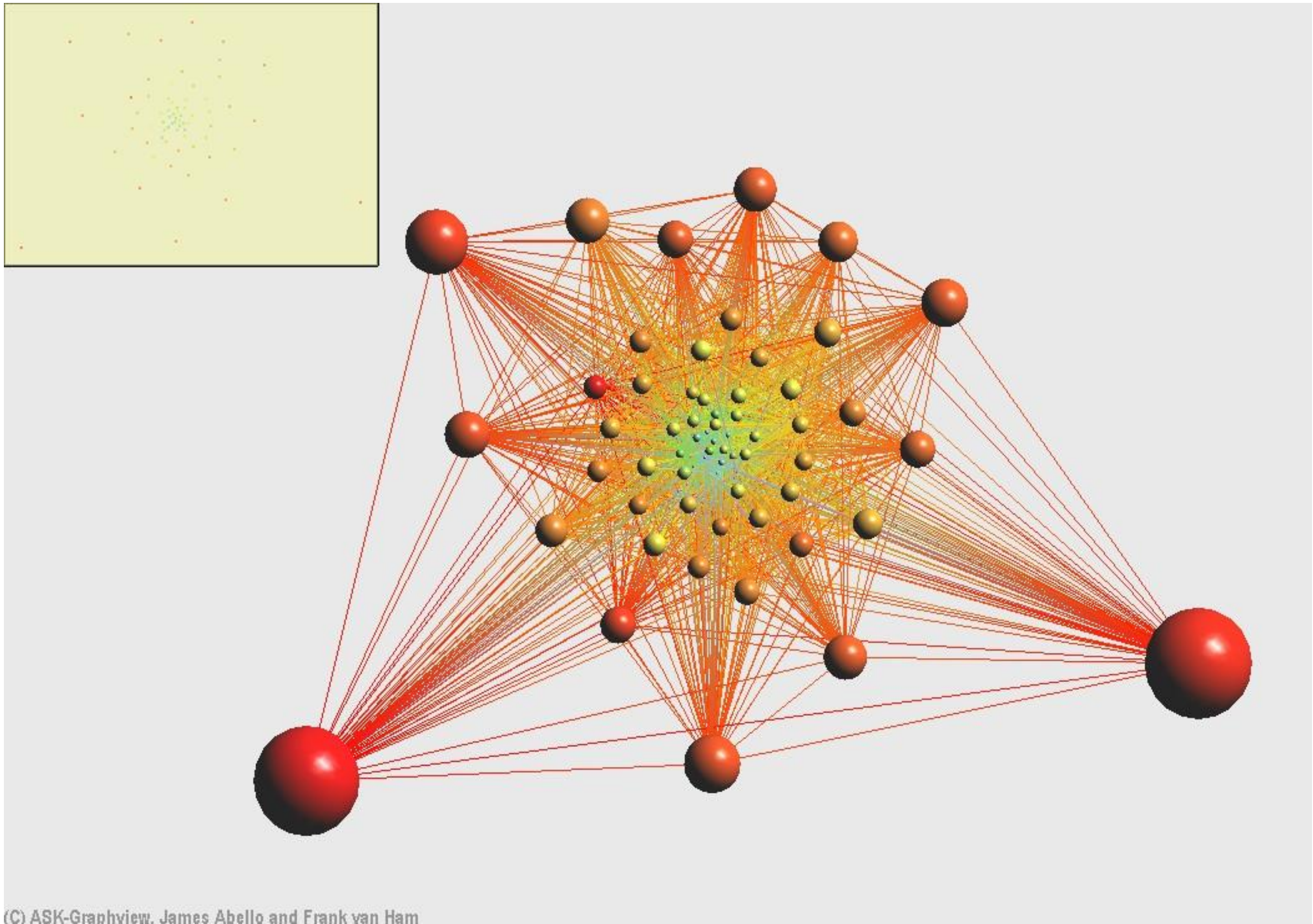
Zooming into Shanghai (gray)

Zooming into a vertex gives more data about traffic



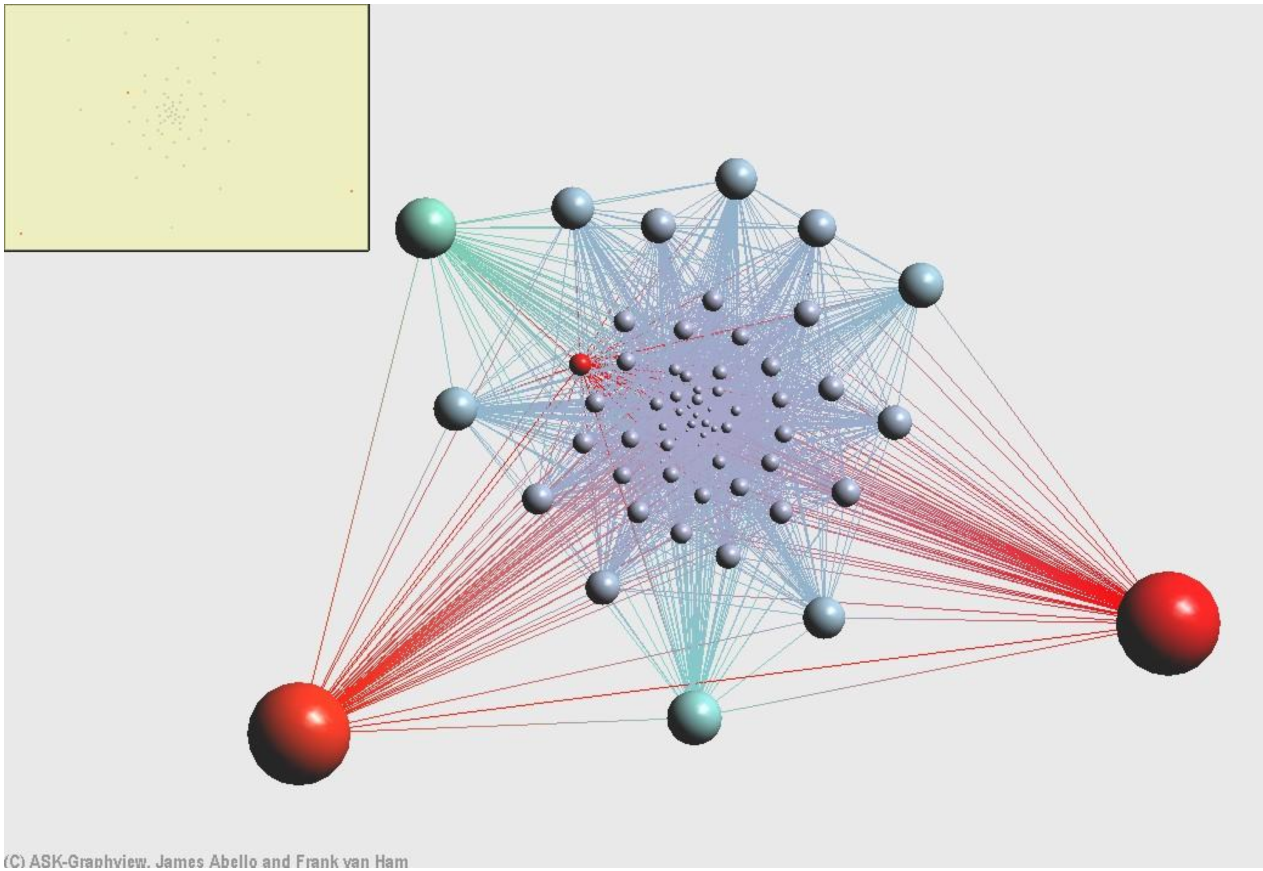
Contents To Port Pairs

Vertices are KeyWords and Port Pairs (color coded by degree), **Edges** encode number of containers (or shipments) with that keyword for the corresponding Port Pair



Contents To Port Pairs (cont)

(Vertices color coded by WeightRatio)



Temporal Evolution of Manifest Data

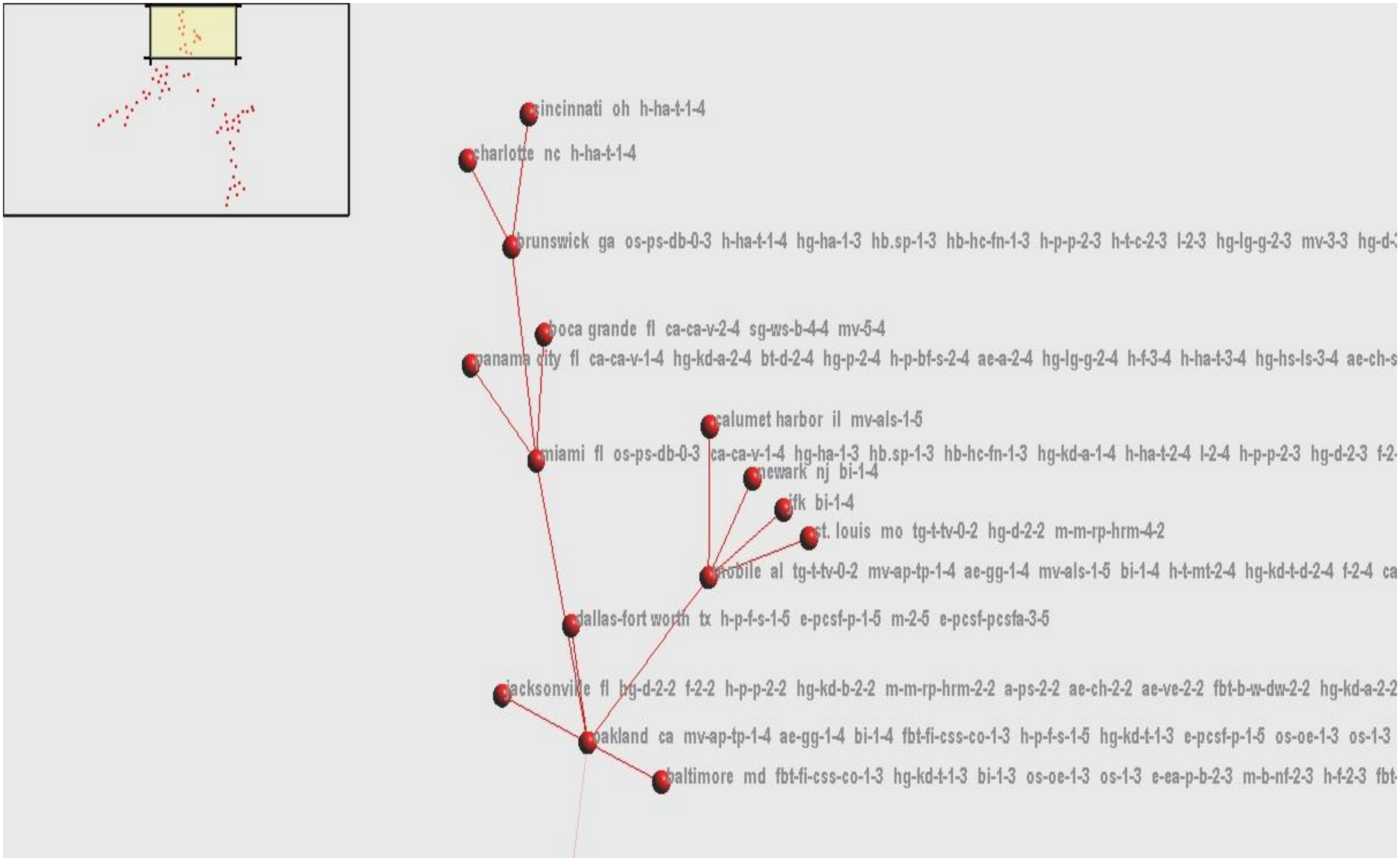
Fix a commodity.

Each vertex represents all shipments from foreign to US ports on a given day.

Cluster by similarity. Notice how all Tuesdays and Wednesdays are well clustered

Can also Cluster by Ports

Note similarity, e.g., Cincinnati, OH and Brunswick, GA



Resilience Modeling

- If a port is damaged or closed, immediate problem of rerouting some or all incoming vessel traffic – if the reopening will be delayed for awhile.
- Also: problem of prioritizing the reopening of the port – and deciding whether and how to reorder ships' arrivals/unloading
- These problems can be subtle.
  - Ice storm shuts down port
  - Maybe priority is unload salt to de-ice. It wasn't a priority before.

Resilience Modeling: One Port

- ***Problem: Reschedule unloading of queued vessels.***

Resilience Modeling: One Port

- ***Problem: Reschedule unloading of queued vessels.***
  - Done by consult with ***shippers*** and their priorities
  - Also consult with key ***government agencies*** to target priority goods or shipments
  - Take into account potential ***spoilage*** of cargo
  - Take into account acute ***shortage*** of key items: food, fuel, medicine, etc.
  - Thus: ***Many variables*** to take into account and juggle
  - Want ***systematic methods***; don't want one stakeholder to feel that only other stakeholders' views were taken into account.
  - Methods of algorithmic decision theory can help
  - So far, just beginning to define the problem and identify the key challenges in developing decision support tools

Resilience Modeling: One Port

- ***Problem: Reschedule unloading of queued vessels.***
- Think of a ship as corresponding to a vector $x = (x_1,x_2,\ldots,x_n)$ where x_i is quantity of i^{th} good.
- Assume all x_i are integers.
- Suppose for simplicity that each ship takes the same amount of time to unload. Then we can give each ship a ***timeslot*** for unloading.
- The port's capacity determines how many ships can be scheduled at a given timeslot.
- Suppose we require d_i units of good i by timeslot t_i.
- $d = (d_1,d_2,\ldots,d_n)$, $t = (t_1,t_2,\ldots,t_n)$.
- In practice, require d_{i1} units of good i by timeslot 1, d_{i2} units of good i by timeslot 2, etc. Disregard this.
- ***How do we assign ships to timeslots?***

Resilience Modeling: One Port

There are some ***subtleties***:

- The manifest data is unclear. If i is water, $x_i = 150$ could mean 150 bottles of water or 150 cases of bottles of water.
- The manifest data is unclear: Descriptions like "household goods" are too vague to be helpful
- Different goods have different ***priorities***. For example, not having enough food, fuel or medicine is much more critical than not having enough bottles of water.
- Let p_i = the priority assigned to good i, with $p = (p_1, p_2, \ldots, p_n)$.

Resilience Modeling: One Port

There are some ***subtleties***:

- There are ***penalties for late arrivals of goods***.
- Sometimes there are ***even penalties for early arrivals*** (storage space issues)
- The penalty can depend on the priorities.

Resilience Modeling: One Port

We encountered a similar problem in working for the Air Mobility Command of the US Air Force.

- Fly soldiers from point A to point B
- Each has desired arrival time
- Getting a general there late is worse than getting a private there late

Similar problems also arise in machine scheduling.

We speak of machine scheduling with earliness and tardiness penalties = "***just in time scheduling***"

Resilience Modeling: One Port

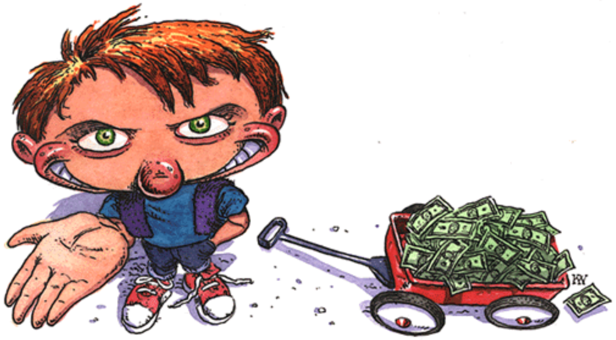
- We have been looking at the simplified problem with all $d_i = 1$ (we demand exactly one unit of each good).
- Then we can talk about the first time a ship carrying good i is scheduled, S_i.
- Let $S = (S_1, S_2, \ldots, S_n)$

Resilience Modeling: One Port

- We are looking at a number of different objective functions F(S,t,p) that need to be optimized.
- Let ***tardiness*** $T_i = \max\{0, S_i - t_i\}$, ***earliness*** $E_i = \max\{0, t_i - S_i\}$.
- For example:
  - $F(S,t,p) = \swarrow p_i T_i + \swarrow p_i E_i$
  - $F(s,t,p) = \swarrow p_i T_i$
  - $F(s,t,p) = \swarrow h(p_i) T_i$
  - $F(s,t,p) = \max\{h(p_1)T_1, h(p_2)T_2, \ldots, h(p_n)T_n\}$

Resilience Modeling: One Port

- A very special case:
  - Only one ship can be unloaded at a time
  - Each ship carries only one kind of good
  - All goods have the same desired arrival time, ♦
- Let $F(S,t,p) =$ ↙$h(p_i)T_i$, $h(p_i)$ increasing in p_i.
- Then a ***greedy algorithm*** gives the optimal unloading schedule: Schedule the highest priority good for first arrival, then the second highest priority good,

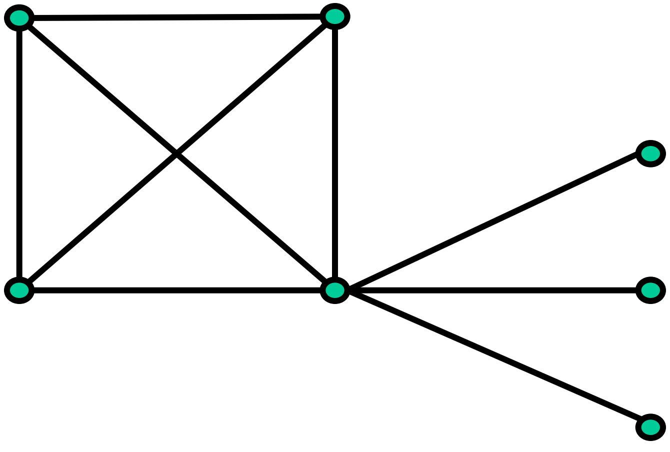


Resilience Modeling: One Port

- Now allow more than one good per ship, but still:
  - Only one ship can be unloaded at a time
  - All goods have the same desired arrival time, ♦
- Let F(S,t,p) = ↙$h(p_i)T_{i,}$ $h(p_i)$ increasing in p_i.
- Ship 1 has x = (1,0,0,0), ship 2 has x = (0,1,0,0), ship 3 has x = (0,0,1,1)
- ♦ = 2
- $p_1 > p_2 > p_3 > p_4$
- Now greedy algorithm would take ship 1 first, then ship 2, then ship 3.
- The penalty for this schedule is $h(p_3) + h(p_4)$.
- But: scheduling ship 1 first, then ship 3, then ship 2 has penalty $h(p_2)$, which might be smaller.
- ***The problem is subtle and even in this special case not simple to solve.***

Resilience Modeling: One Port

- Now allow exactly two goods per ship
  - The port has capacity for only one ship at a time.
- This translates into a graph theory problem where ships correspond to edges, goods to vertices, and we want to order the edges in such a way that every vertex gets assigned a timeslot that corresponds to the earliest timeslot of any edge it belongs to.



Resilience Modeling: Simplifications

- All desired amounts are one unit, i.e., $d_i = 1$, all i.
- Reopened port has limited capacity of one ship per timeslot
- All goods have the same desired arrival time ♦
- All goods have only one desired arrival time rather than portion desired by time 1, some by time 2, etc.
- All ships have same unloading time.
- All ships are ready to dock without delay
- There is no problem storing unloaded but not urgently-demanded goods
- Each ship has only one kind of good

Even making all or most of these assumptions leads to a complex scheduling problem

Resilience Modeling: Rerouting to Nearby Ports

- Problem: If a port can't be reopened soon, incoming ships must go to other ports.
- As a general rule, where they go is left to shippers/vessel operators
- However, can we develop a decision support tool that will allow us to provide guidance to shippers and take into account the need to deliver critical supplies?
- Goals: minimize economic impact of delay and security impact of delay in delivery of critical supplies.
- Start with one nearby port; then try two ports
- This work is planned.
- Step one is to identify priorities for where goods are to be delivered.

Determining the Priorities

- How do we determine the priorities as to where different goods are to be delivered?
- One approach: each stakeholder (government, port operators, shippers) provides their priorities and some ***consensus or voting procedure*** is used to "average" them.

Determining Desired Times for Unloading

- Explore "bidding system" for setting times to unload vessels.
- After government or central entity sets desired times for delivery of critical products, companies receiving shipments make bids for earliest arrival dates.
- Problem is complicated by mixed collection of goods in any container.
- Based on priorities and bids, find ways to do "optimal" rerouting.

Determining Desired Times for Unloading

- The "bidding" system gets into the mathematical analysis of auctions.
- A topic of a great deal of research in mathematics and computer science.
- Information technology allows complex auctions with a huge number of bidders.
- ***Bidding protocols maximizing expected profit can be extremely difficult to compute.***

Determining Desired Times for Unloading

- Multiple goods are to be auctioned off.

- In practice, you submit bids for combinations of goods.
- This leads to NP-complete allocation problems.
- Might not even be able to feasibly express all possible preferences for all subsets of goods.
- Then: Determining the winner of an auction can be extremely hard. (Rothkopf, Pekec, Harstad)

Determining Desired Times for Unloading

- In these complicated "***combinatorial auctions***," we need to elicit preferences from all "players" for all plausible combinations of items in the auction.
- Similar problem arises in optimal bundling of goods and services.
- Elicitation requires exponentially many queries in general.
- Thus, ***bidding procedures to aid in reopening closed ports lead to challenges for modern methods of ADT.***

Collaborators

- **Data Visualization**
  – James Abello, Tsvetan Asamov
- **Decision Support for Reopening a Port**
  - Paul Kantor, Endre Boros, Tsvetan Asamov, Emre Yamangil
- **Bidding Systems**
  - Paul Kantor, Aleksandar Pekec

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