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Monitoring Radiation Exposure With DICOM and Splunk

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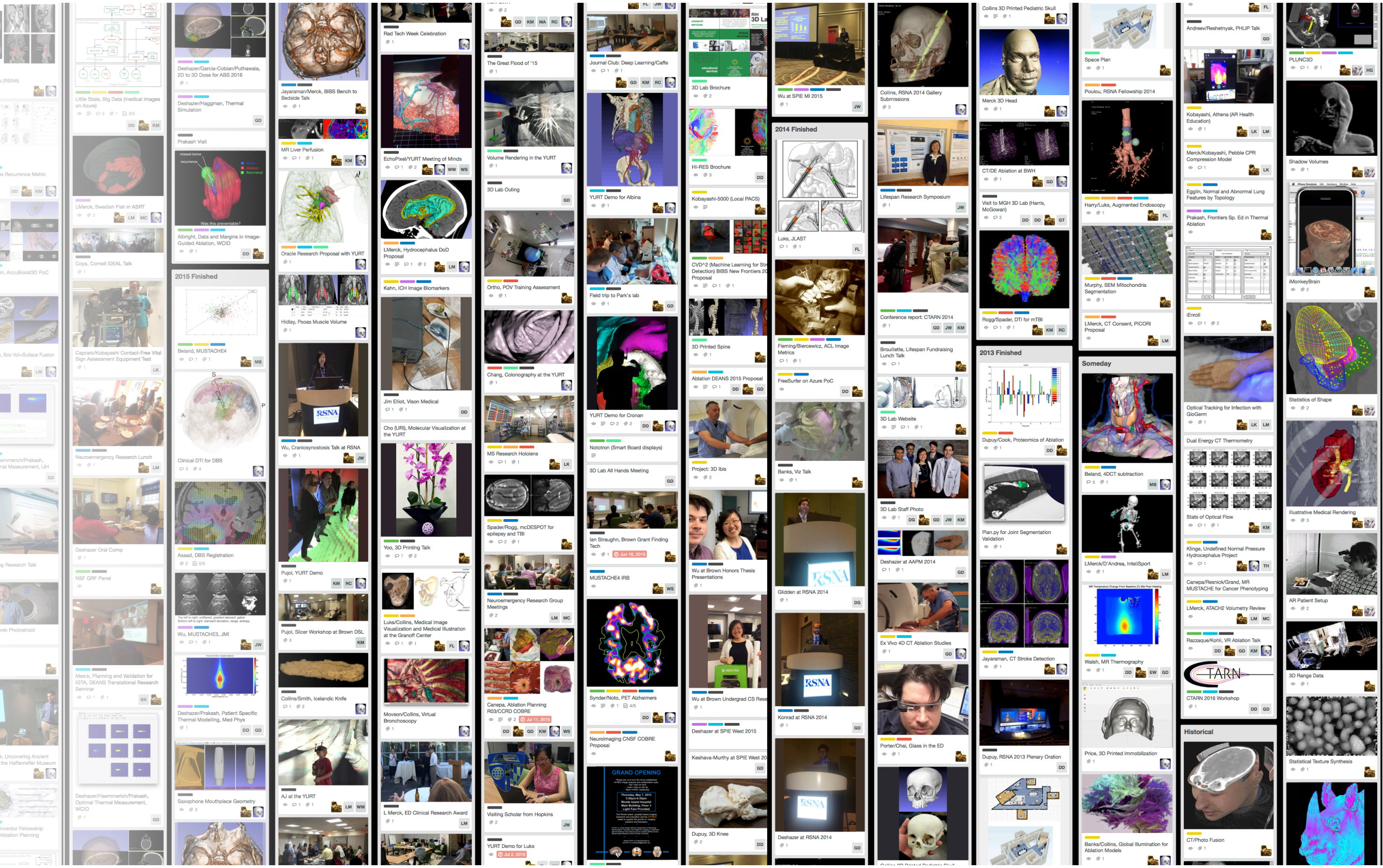
- Splunk4Good (Corey Marshall)

The RIH 3D Lab

- Medical imaging and informatics research
- Post-graduate academic training
- Unique clinical work-ups and procedure planning



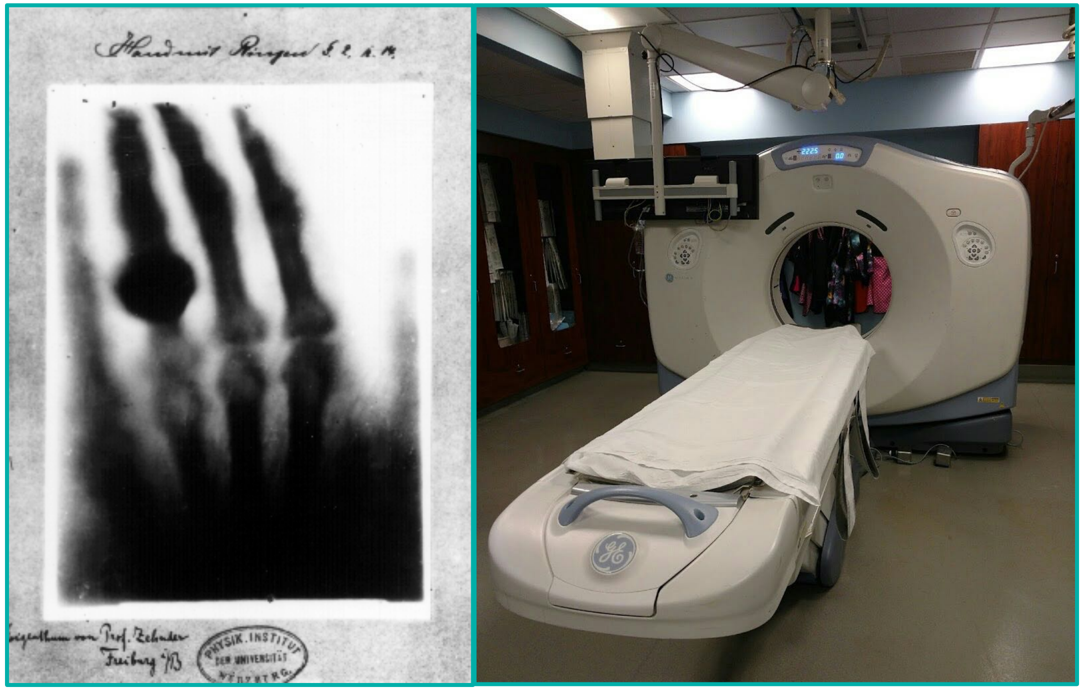
Overview

- Radiation-based medical imaging
  - X-rays and computed tomography
  - Responsible radiation use
- Dose monitoring with open source tools and Splunk
  - DICOM
  - Bridging DICOM to JSON
  - Network organization
  - Effective queries for DICOM tags
- Improved Quality Assurance
  - Dose dashboards
  - Outlier alerts
  - Creating an audit trail
  - Scaling out to additional devices
- Radiology workflow analysis with Splunk
  - Device utilization
  - Workload prediction using HL7

Radiation-Based Medical Imaging

X-Rays and Computed Tomography

- Film x-ray has been around since the late 19th century
- Computed tomography was developed in the 1970s
  - Uses x-ray images from multiple angles to estimate x-ray attenuation inside a volume
  - Since different tissue types attenuate x-rays differently, this effectively shows anatomy



Rontgen’s wife’s hand (1896) and a modern 64-slice CT scanner at RIH.

X-Rays and Computed Tomography

70mGy vs. 23mGy exposure for similar studies
ALARA Principle: “As Low As Reasonably Achievable”
Noise and low anatomic differentiation is ok sometimes

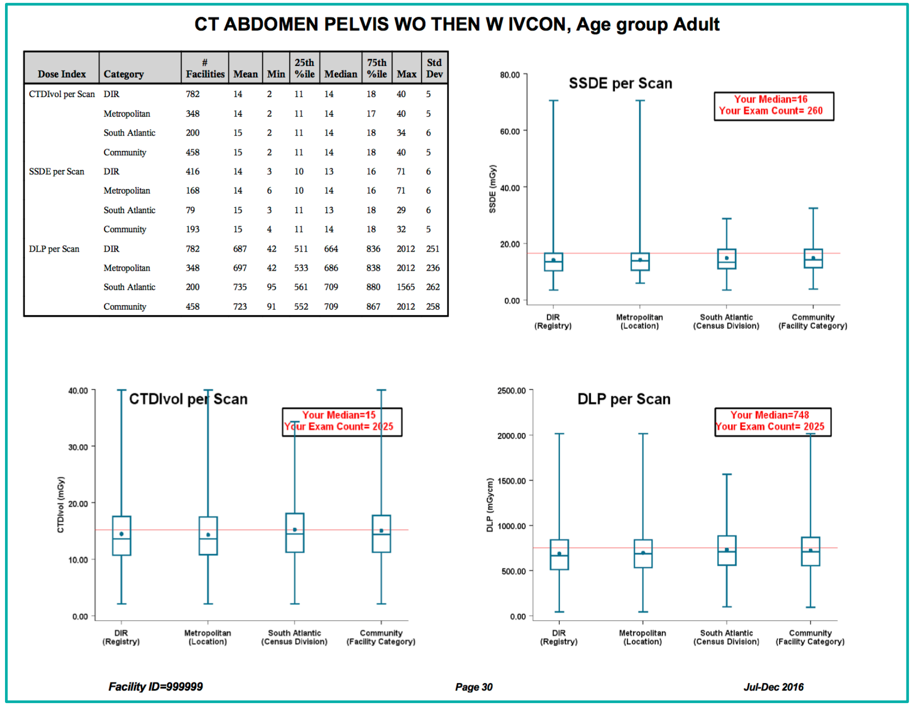
X-Rays and Computed Tomography

- More radiation = more precise reconstruction and more useful data for patient care
- More radiation = more chance of injuring the patient
  - Directly, by burning them
  - Indirectly, by raising their risk for cancer
- Incident at Cedar-Sinai in 2009 (3) resulted in new rules

Improperly performed perfusion studies at Huntington, WV, in 2011 (11) caused focal hair loss.

Responsible Use of Radiation

- Hospitals must routinely prove that we are using radiation responsibly
- Otherwise the Joint Commission could reduce how much we are reimbursed for imaging studies (2)
- Currently done by sending “radiation dose reports” for all studies to a third party system
  - American College of Radiologists (ACR) registry provides quarterly summaries, but its difficult to actually identify outliers
  - Commercial systems provide on-demand analysis, but they cost $100k/year



CT ABDOMEN PELVIS WO THEN W IVCON, Age group Adult

Dose Index	Category	# Facilities	Mean	Min	25th %ile	Median	75th %ile	Max	Std Dev
CTDIvol per Scan	DIR	782	14	2	11	14	18	40	5
	Metropolitan	348	14	2	11	14	17	40	5
	South Atlantic	200	15	2	11	14	18	34	6
	Community	458	15	2	11	14	18	40	5
SSDE per Scan	DIR	416	14	3	10	13	16	71	6
	Metropolitan	168	14	6	10	14	16	71	6
	South Atlantic	79	15	3	11	13	18	29	6
	Community	193	15	4	11	14	18	32	5
DLP per Scan	DIR	782	687	42	511	664	836	2012	251
	Metropolitan	348	697	42	533	686	838	2012	236
	South Atlantic	200	735	95	561	709	880	1565	262
	Community	458	723	91	552	709	867	2012	258

A sample ACR report: great if everything is ok, but not very helpful in mitigating problems.

Challenge: Create an inexpensive, effective dose monitoring system that can be managed in-house without a dedicated IT person

Dose Monitoring with Open Source Tools and Splunk

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DICOM

- CT scanners generate images and metadata using the woefully archaic DICOM format
- Detailed technology and patient metadata embedded directly in the image header as numeric “tags”
- Also a set of network protocols that allow machines to interoperate
- DICOM-friendly systems are all meant for patient care, not for data analysis
- Need to transform DICOM headers into data

```
0018,1000 (DeviceSerialNumber): W4A1182121
0018,1020 (SoftwareVersions): V4.50*R003
0020,000d (StudyInstanceUID):
1.2.392.200036.9116.3.1.11582121.3000017062722515201500000005
0020,000e (SeriesInstanceUID):
1.2.392.200036.9116.3.1.11582121.3000017062722532540600000002
0020,0010 (StudyID): XA20170627185555
0020,0011 (SeriesNumber): 9001
0020,0013 (InstanceNumber): 185845
0032,000a (RETIRED_StudyStatusID): COMPLETED
0032,000c (RETIRED_StudyPriorityID):
0040,a040 (ValueType): CONTAINER
▸ 0040,a043 (ConceptNameCodeSequence): []
0040,a050 (ContinuityOfContent): SEPARATE
0040,a372 (PerformedProcedureCodeSequence): []
0040,a491 (CompletionFlag): PARTIAL
0040,a493 (VerificationFlag): UNVERIFIED
▸ 0040,a504 (ContentTemplateSequence): []
▾ 0040,a730 (ContentSequence): []
    ▾ Item 0
        0040,a010 (RelationshipType): HAS CONCEPT MOD
        0040,a040 (ValueType): CODE
      ▸ 0040,a043 (ConceptNameCodeSequence): []
      ▾ 0040,a168 (ConceptCodeSequence): []
          ▾ Item 0
              0008,0100 (CodeValue): 113704
```

DICOM format is key/value driven by cryptic numeric tags, only accessible through DICOM viewers.

Bridging DICOM to JSON

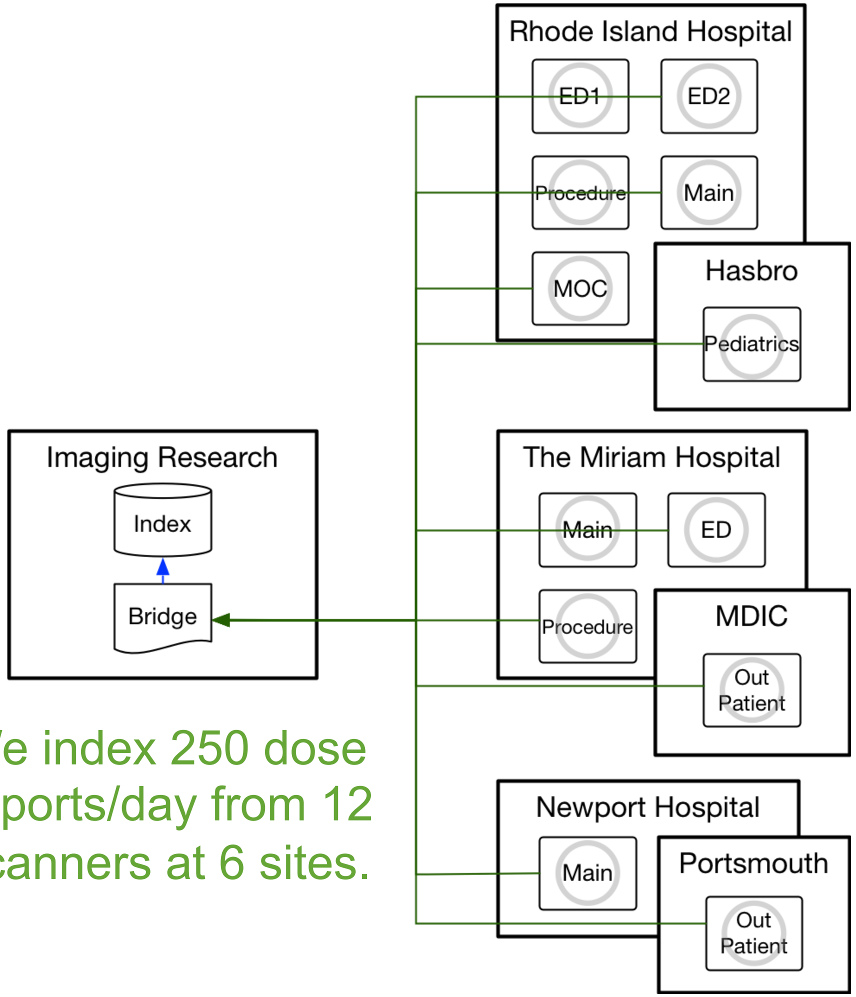
- Orthanc, an open source DICOM server and image database
- Accepts data in DICOM
- Can be controlled via a REST interface
- Still no capability for complex data analytics
- But, effectively translates most DICOM tags into JSON (but not dose)
- And can be modified to translate dose tags into JSON as well


```
"InstanceCreatorUID" : "1.2.392.200036.9116.3.1.11582121",
"InstanceNumber" : "185845",
"Manufacturer" : "TOSHIBA_MEC",
"ManufacturerModelName" : "DFP-8000D",
"Modality" : "SR",
"Occupation" : "",
"PatientAge" : "093Y",
"PatientBirthDate" : "19230730",
"PatientID" : "0123test",
"PatientName" : "test^RDSRxfer",
"PatientSex" : "M",
"PerformedProcedureCodeSequence" : [],
"RETIRED_StudyPriorityID" : "",
"RETIRED_StudyStatusID" : "COMPLETED",
"ReferencedPerformedProcedureStepSequence" : [
   {
      "ReferencedSOPClassUID" : "1.2.840.10008.3.1.2.3.3",
      "ReferencedSOPInstanceUID" :
1.2.392.200036.9116.3.1.11582121.300001706272251522500000001"
   }
],
"ReferringPhysicianName" : "",
"SOPClassUID" : "1.2.840.10008.5.1.4.1.1.88.67",
"SOPInstanceUID" :
1.2.392.200036.9116.3.1.11582121.300001706272253254060000003",
"SeriesInstanceUID" :
1.2.392.200036.9116.3.1.11582121.300001706272253254060000002",
"SeriesNumber" : "9001",
"SoftwareVersions" : "V4.50*R003",
"StudyDate" : "20170627",
"StudyDescription" : "",
"StudyID" : "XA20170627185555",
"StudyInstanceUID" :
```


Same data liberated by replacing numeric tags with intuitive identifiers and transforming format to a generic dictionary structure.

Network Organization

- Scanners talk to an Orthanc node
- Python script acts as a bridge
  - Requests DICOM dose information from Orthanc in JSON format
  - Pushes JSON to Splunk index
- Once data are in Splunk, they can be used for analysis



We index 250 dose reports/day from 12 scanners at 6 sites.

Effective Queries for DICOM Tags

- Need to address the limitations of the data format
  - **Normalizing DICOM tags that are used by different vendors in different ways**
  - Splitting up multiple radiation events within each dose report
  - Lookup maps between unintuitive data and simple names
    - scanner s/n→ location
    - procedure code → body part

```
spath "X-ray Radiation Dose Report.CT Accumulated Dose Data.CT Dose Length Product Total" |
spa[illegible] |
spath "X-ray Radiation Dose Report.CT Acquisition{}.CT Acquisition Type" |
spath [illegible]quisition{}.CT Acquisition Type" |
lookup device_map.csv StationName OUTPUT InstitutionName Modality Location Manufacturer RPDField |
where [illegible]onName, ".*") |
search PatientAge>="018Y" AND PatientAge<"199Y" |
eval name=InstitutionName." ".Location." (".Manufacturer.")" |
eval RPD=if(RPDField=="StudyDescription",
    StudyDescription,
    coalesce(RequestedProcedureDescription, 'ProcedureCodeSequence{}.CodeMeaning', 'RequestAttributesSequence{0}.RequestedProcedureDescription')) |
lookup rpd_map.csv RPD OUTPUT BodyPart Impact |
eval age="adult" |
eval bodypart="head" |
lookup "review_thresholds.csv" age bodypart
    OUTPUT aapm AS AAPM acr_median as ACR_MEDIAN acr_25th AS ACR_25TH thresh color_lut |
```

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```
eval RPD=substr(RPD,1,33) |
rename "X-Ray Radiation Dose Report.CT Acquisition{}.CT Acquisition Type" AS acq_type,
  "X-Ray Radiation Dose Report.CT Acquisition{}.CT Dose.Mean CTDIvol" AS mean_CTDIvol |
eval x=mvzip(acq_type, mean_CTDIvol, ",") |
mvexpand x | eval x=split(x,",") |
eval acq_t=mvindex(x,0) | eval mean_CTDIvol=mvindex(x,1) |
search acq_t="Spiral Acquisition" |
eval sig_mean_CTDIvol=mean_CTDIvol |
```

Effective Queries for DICOM Tags

- Need to address the limitations of the data format
  - Normalizing DICOM tags that are used by different vendors in different ways
  - Splitting up multiple radiation events within each dose report
  - **Lookup maps between unintuitive data and simple names**
    - scanner s/n→ location
    - procedure code → body part

```
spath "X-ray Radiation Dose Report.CT Acquisition{}.CT Acquisition Type" |
spath "X-Ray Radiation Dose Report.CT Acquisition{}.CT Acquisition Type" |
lookup device_map.csv StationName OUTPUT InstitutionName Modality Location Manufacturer RPDField |
where match(InstitutionName, ".*") AND match(StationName, ".*") |
search PatientAge>="018Y" AND PatientAge<"199Y" |
eval name=InstitutionName." ".Location." (".Manufacturer.")" |
eval RPD=if(RPDField=="StudyDescription",
    StudyDescription,
    coalesce(RequestedProcedureDescription, 'ProcedureCodeSequence{}.CodeMeaning', 'RequestAttributesSequence{0}.RequestedProcedureDescription')) |
lookup rpd_map.csv RPD OUTPUT BodyPart Impact |
```

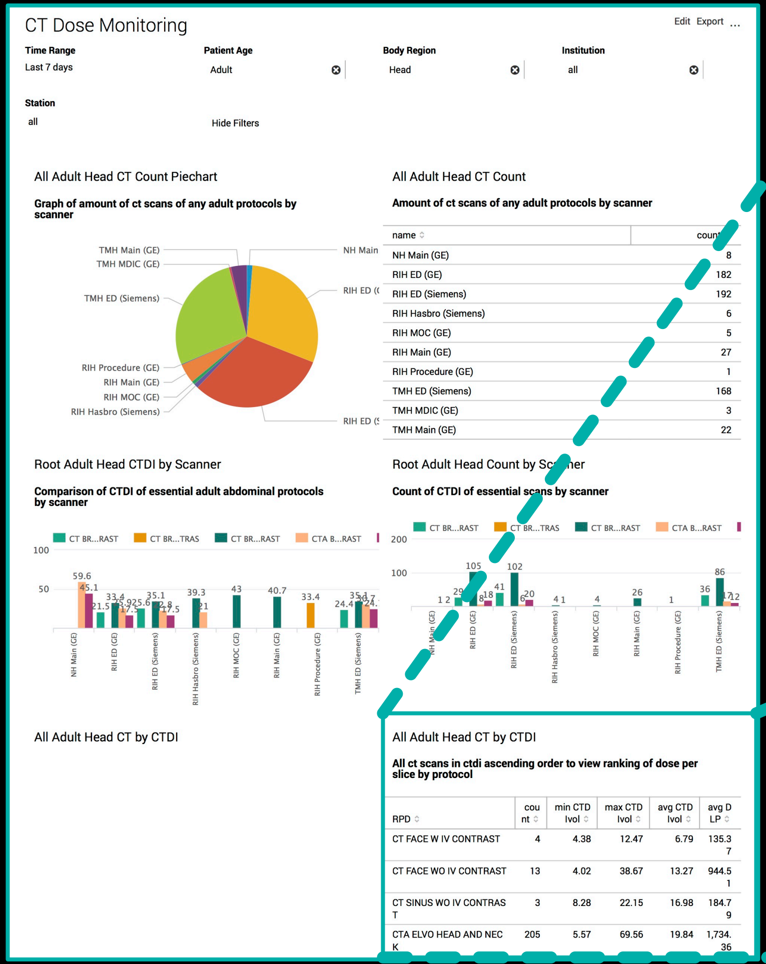
Improving Quality Assurance

Dashboards

- Traditional radiation QA has very high latency (monthly or quarterly)
- ACR reports only show that outliers exist
  - Do not identify where/why/how to fix
- Now service managers print Splunk dashboards
  - Do identify where/why/how to fix
- Even better, they want to use the dashboards interactively for QA

Dashboards

Radiation Exposure Summary



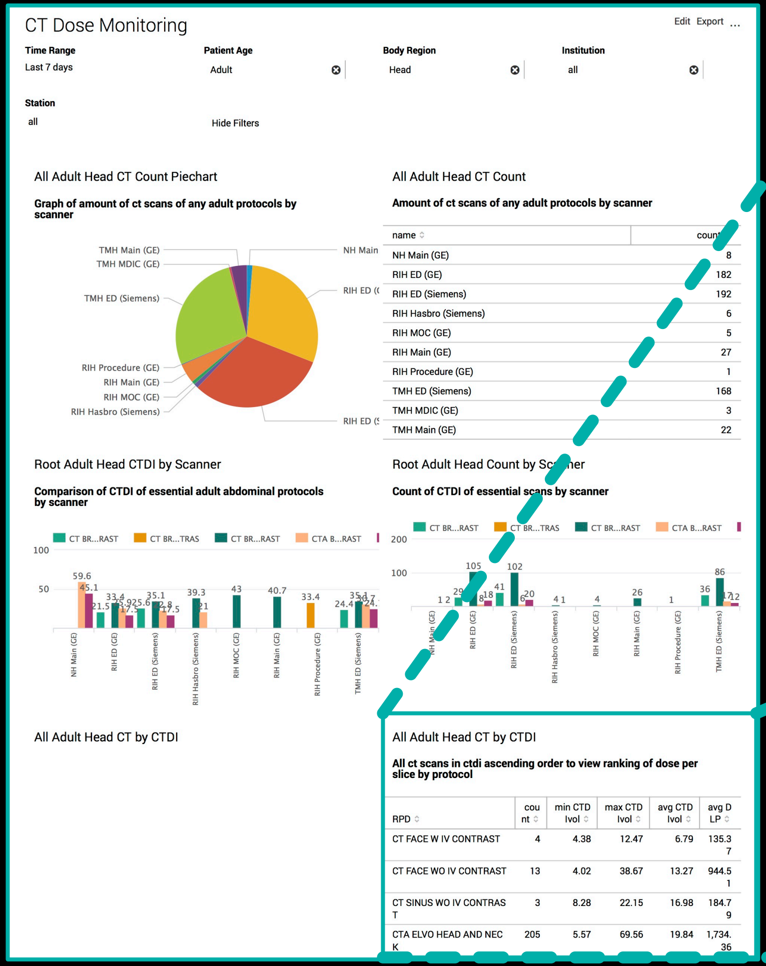
All Adult Head CT by CTDI

All ct scans in ctdi ascending order to view ranking of dose per slice by protocol

RPD	count	min CTDIvol	max CTDIvol	avg CTDIvol	avg DLP
CT FACE W IV CONTRAST	4	4.38	12.47	6.79	135.37
CT FACE WO IV CONTRAST	13	4.02	38.67	13.27	944.51
CT SINUS WO IV CONTRAST	3	8.28	22.15	16.98	184.79
CTA ELVO HEAD AND NECK	205	5.57	69.56	19.84	1,734.36

Dashboards

Radiation Exposure Summary



All Adult Head CT by CTDI

All ct scans in ctdi ascending order to view ranking of dose per slice by protocol

RPD	cou nt	min CTD Ivol	max CTD Ivol	avg CTD Ivol	avg D LP
CT FACE W IV CONTRAST	4	4.38	12.47	6.79	135.37
CT FACE WO IV CONTRAST	13	4.02	38.67	13.27	944.51
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CTA ELVO HEAD AND NECK	205	5.57	69.56	19.84	1,734.36

Dashboards

Radiation Exposure Drilldown

DI

ng order to view ranking of dose per

cou nt	min CTD Ivol	max CTD Ivol	avg CTD Ivol	avg D LP
4	4.38	12.47	6.79	135.37
13	4.02	38.67	13.27	944.51
3	8.28	22.15	16.98	184.79
205	5.57	69.56	[illegible]	1,734.36

StudyDateTime: 2017-08-19T12:10:02
StudyDescription: CTA ELVO HEAD AND NECK
StudyID: 17326
StudyInstanceUID: 1.2.840.113619.2.404.3.2299185167.25.1503118643.704
StudyTime: 121002
Unknown Tag & Data: CT Scanner
ValueType: CONTAINER
VerificationFlag: UNVERIFIED
X-Ray Radiation Dose Report: { [-]
  CT Accumulated Dose Data: { [+]
  }
  CT Acquisition: [[-]
    { [+]
    }
    { [+]
    }
    { [+]
    }
    { [+]
    }
    { [-]
      Acquisition Protocol: 1.8 MULTI-PHASE ELVO CTA Head and Neck
      CT Acquisition Parameters: { [+]
      }
      CT Acquisition Type: Spiral Acquisition
      CT Dose: { [-]
        CTDIw Phantom Type: IEC Head Dosimetry Phantom
        DLP: 1472.71
        Dose Check Alert Details: { [+]
        }
        Dose Check Notification Details: { [+]
        }
        Mean CTDIvol: 69.56
      }
      Irradiation Event UID: 1.2.840.113619.2.404.3.2299185167.25.1503118643.717

Daily Reports and Alerts

- Data confirms that we *never* go over allowable radiation dose
- But there are outliers with higher than expected dose for a given procedure
- Now that we can identify outliers, we can automatically generate meaningful reports and alerts
- Monthly QA reference reports can go out as PDFs to administration
- Real-time alerts can be sent by email, Slack, or Twillio to service managers

Creating an Audit Trail

- Now that we are identifying and responding to outliers, we need an audit trail
- Created another form dashboard that allows managers to comment on incidents, mark them open or closed, and print incident logs filtered by different categories
- Simple, but replaces multiple hand-maintained Excel spreadsheets from different services and hospitals with a unified system
- 1 year ago I asked the chief technology officer, “How many radiation exposure outliers do we have in a year?” and he said, “Never”
  - Yes, we never have *significant* incidents (because our staff is awesome)
  - However, we do have a couple of minor outliers each week that are usually justified (i.e., additional imaging required) or are addressed through engineering or staff education
  - Now these are logged, rather than dealt with informally

Dashboards

Tracking Exposure Outliers

CT Dose Monitoring | VIR Dose Monitoring | Dose Outliers | Search | Reports | Dashboards | Dose Monitoring

Edit | Export | ...

Dose Outliers

Review of CT studies with relatively high helical CTDI

Accession Number | Reason | Comment | Status | Submit | Hide Filters

Pressing "submit" updates an incident and audit trail immediately. You may need to refresh the incident log manually (rollover button at the bottom) to see status updates and new comments. The same rollover provides a manual download link to create a csv file from the listed events.

Incident Log

Time Range: Last 7 days | Institution: all | Reason: all | Status: all

_time	AccessionNumber	PatientID	RPD	Max CTDI	DLP	InstitutionName	Device	OperatorsName	users	reason	comments	status
2017-08-18 01:27:24			CT BRAIN WO IV CONTRAST	50.11	1164.88	RIH	ED (Siemens)	lmm	rih	body habitus		closed
2017-08-17 17:37:56			CT CHEST ABDOMEN PELVIS W IV CONTRAST	25.36	1766.11	RIH	Main (GE)		rih	body habitus	327 lbs	closed
2017-08-17 11:14:34			CT BRAIN WO IV CONTRAST	54.04	984.67	RIH	MOC (GE)		rih	body habitus		closed
2017-08-17 09:31:28			CT CHEST ABDOMEN PELVIS W IV CONTRAST	24.92	1610.53	TMH	Main (GE)		mh	combo study	body habitus	closed
2017-08-17 09:26:46			CT ABDOMEN PELVIS WO IV CONTRAST	24.01	1348.83	TMH	ED (Siemens)	LP	mh	body habitus	140 kvp	closed

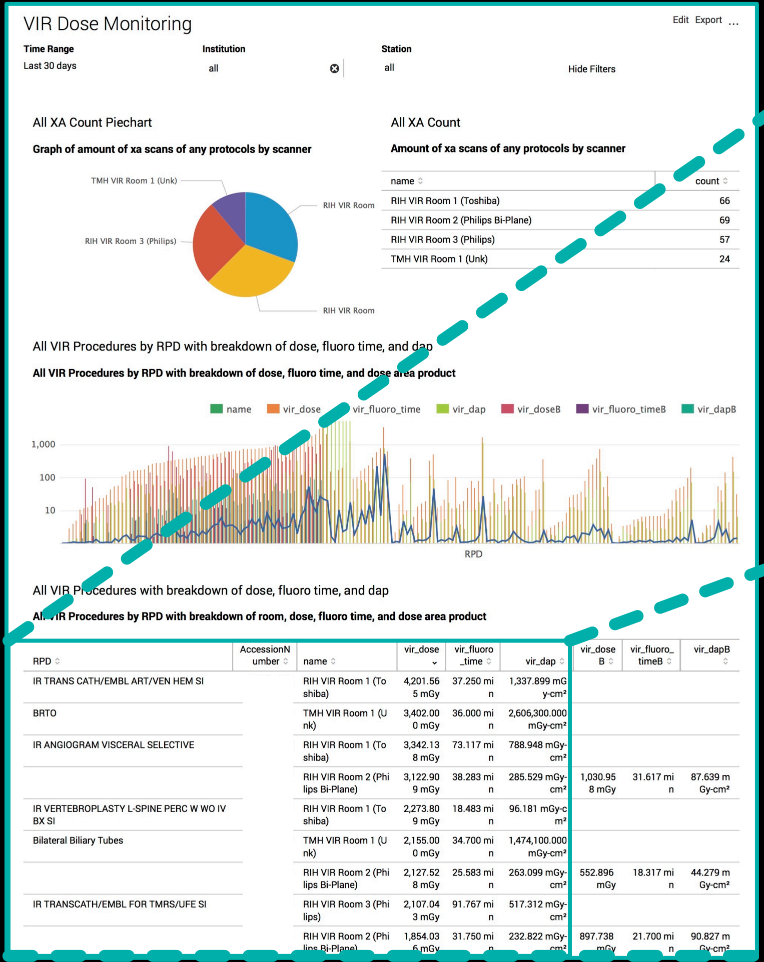
Scaling Out to Additional Devices

- Medicare/Medicaid Services (CMS) visited TMH and asked to see a summary of radiation exposure in our fluoroscopic x-ray suites
  - ”Interventional radiology” is a service that uses real-time x-ray imaging to guide device placement or direct catheters for intravascular procedures
- Play the same game
  - A little bit of network rerouting
  - Normalize the DICOM dose reports
  - Change the units on the dashboards…

Many image-guided procedures are done under constant x-ray exposure, called “fluoroscopy”

Dashboards

Radiation Exposure in Fluoroscopy Procedures



All VIR Procedures with breakdown of dose, fluoro time, and dap

All VIR Procedures by RPD with breakdown of room, dose, fluoro time, and dose area product

RPD	AccessionNumber	name	vir_dose	vir_fluoro_time	vir_dap
IR TRANS CATH/EMBL ART/VEN HEM SI		RIH VIR Room 1 (Toshiba)	4,201.565 mGy	37.250 min	1,337.899 mGy-cm²
BRTO		TMH VIR Room 1 (Unk)	3,402.000 mGy	36.000 min	2,606,300.000 mGy-cm²
IR ANGIOGRAM VISCERAL SELECTIVE		RIH VIR Room 1 (Toshiba)	3,342.138 mGy	73.117 min	788.948 mGy-cm²
		RIH VIR Room 2 (Philips Bi-Plane)	3,122.909 mGy	38.283 min	285.529 mGy-cm²
IR VERTEBROPLASTY L-SPINE PERC W WO IV BX SI		RIH VIR Room 1 (Toshiba)	2,273.809 mGy	18.483 min	96.181 mGy-cm²
Bilateral Biliary Tubes		TMH VIR Room 1 (Unk)	2,155.000 mGy	34.700 min	1,474,100.000 mGy-cm²
		RIH VIR Room 2 (Philips Bi-Plane)	2,127.528 mGy	25.583 min	263.099 mGy-cm²
IR TRANSCATH/EMBL FOR TMRS/UFE SI		RIH VIR Room 3 (Philips)	2,107.043 mGy	91.767 min	517.312 mGy-cm²
		RIH VIR Room 2 (Philips Bi-Plane)	1,854.036 mGy	31.750 min	232.822 mGy-cm²

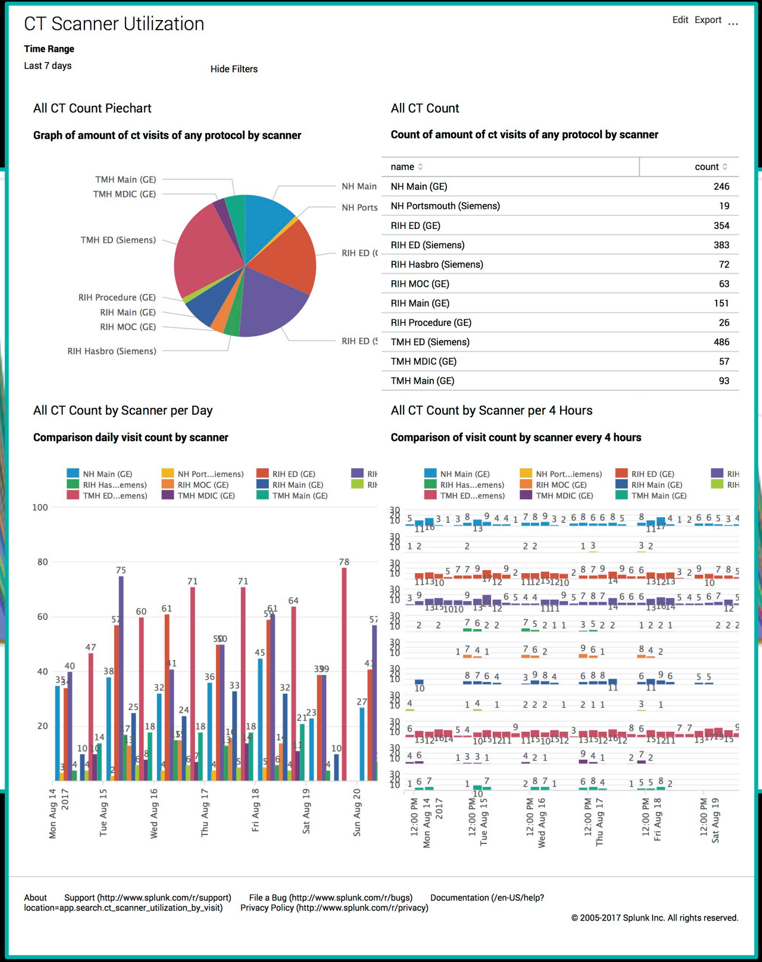
Radiology Workflow Analysis with Splunk

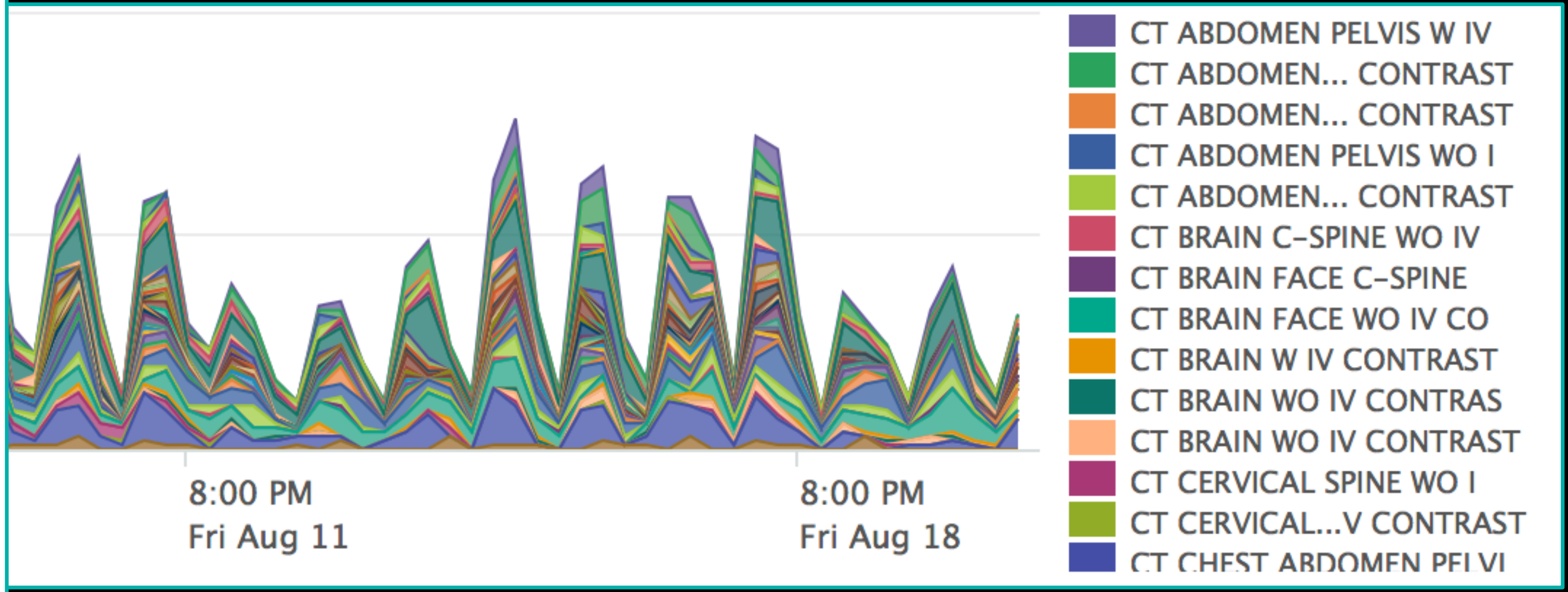
Device Utilization

- An unforeseen side-effect of the system is the ability to do deep utilization analysis
- 1 year ago I asked the chief tech officer, “How many CT scans do we shoot in a year?” and we could only ballpark answers
  - Now we know about every scan and which machine each was done on (all 60k/year across 10 scanners at 3 hospitals)
  - We can even estimate which machines may need x-ray source replacements next
- The CT manager wants to know why the ED was complaining about long wait times for imaging on a particular day
  - We plot number of studies per hour on that day on the ED scanners vs. average number of studies they handle and show that utilization vastly exceeded capacity
  - Now we have *evidence* that only way to fix those wait times is to order another scanner or to divert…

Dashboards

Device Utilization

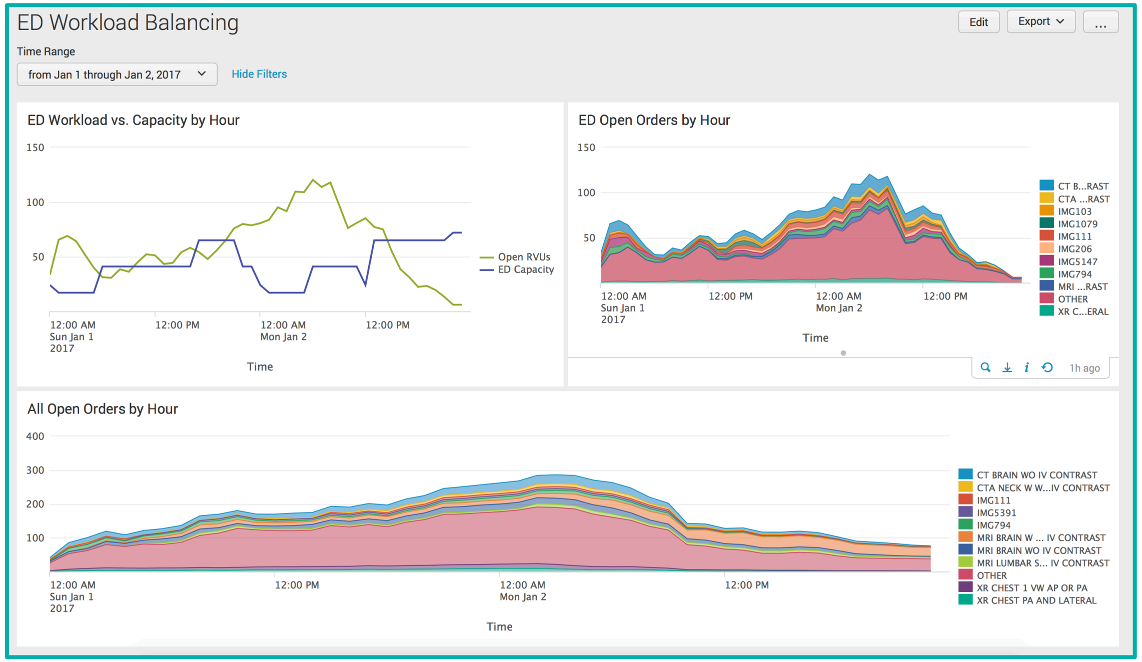




Count by procedure over time

Workload Prediction with HL7

- Next, the CT manager wants to *predict* what those wait times are going to be, so that we can mitigate problems before they occur
- Dose reports only tells us what *was done*, not what *is ordered*
- Then, we need to integrate another data feed from the hospital order system
  - The ordering system uses another archaic format: HL7
- Once the parser and logic is in place, we can predict utilization patterns based on ordering patterns with an hour of lead time



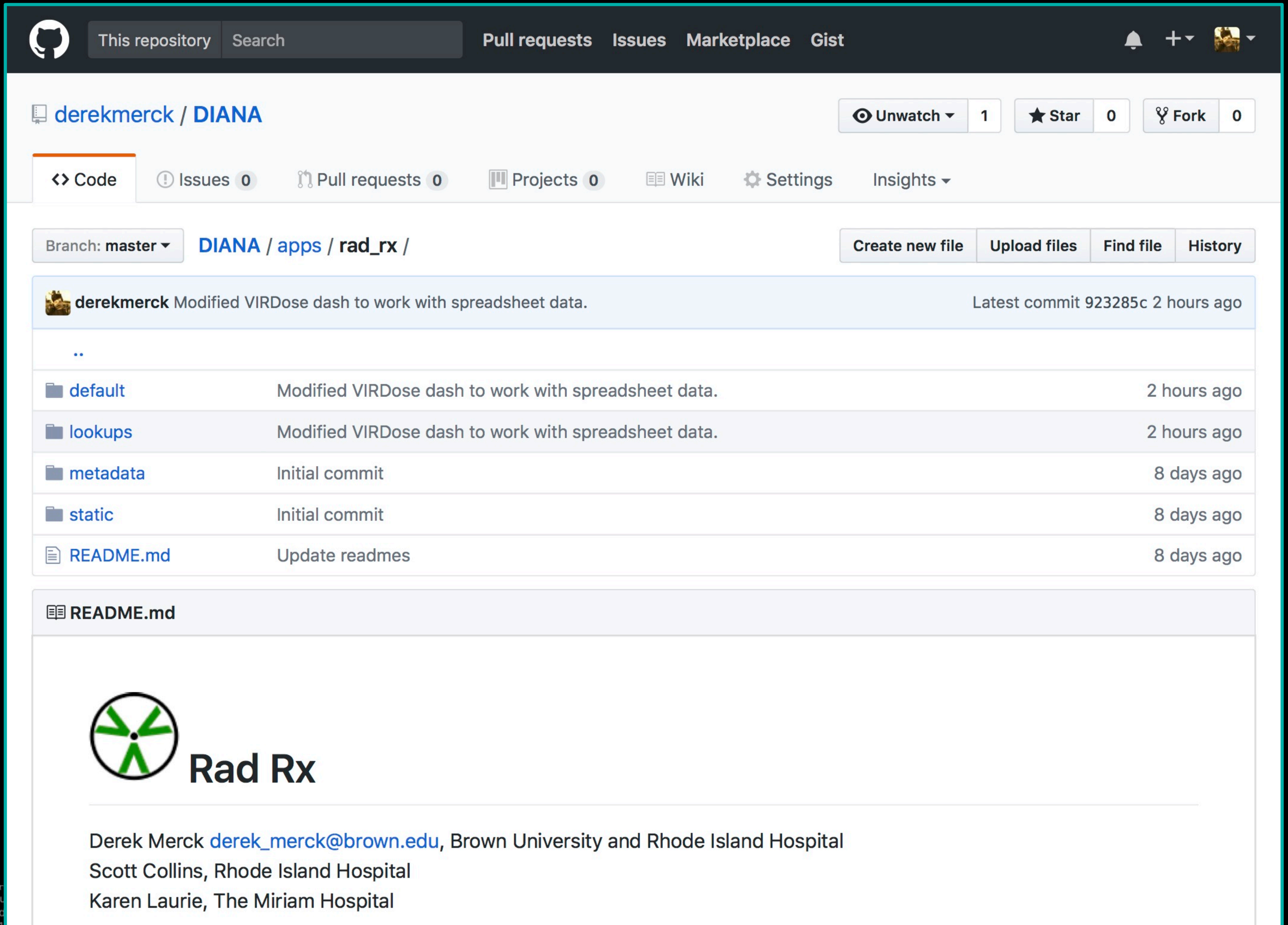
Open orders by hour in ED and system-wide

Key Takeaways

1. Domain data is amenable to Splunk workflows
2. Splunk is a great replacement for under-performing, over-engineered solutions
3. Linking heterogeneous data sources = unforeseen possibilities for systemic optimization

App is on GitHub

http://www.github.com/derekmerck/DIANA



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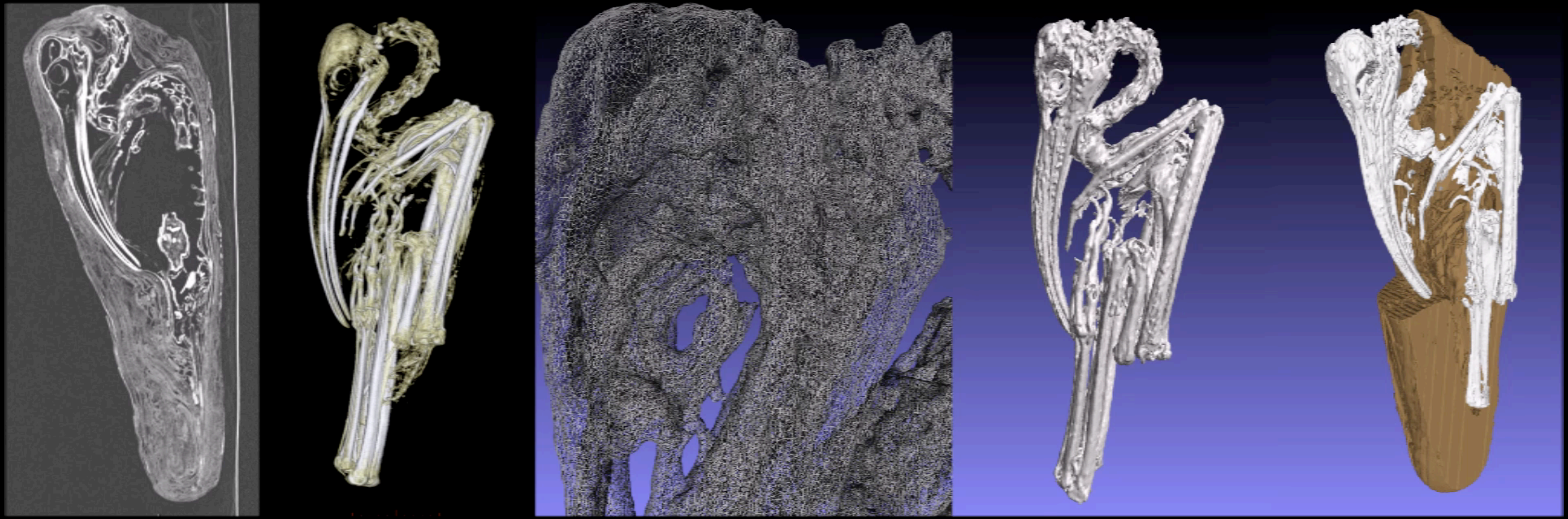
CT Post-Processing



Thank You

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