PERSEUS Program Disseminated Dataset Descriptions and Use Instructions v1.1

.json dataset

The data acquired by the Push Electronic Relay for Smart Alarms for End User Situational Awareness [PERSEUS] research program are being shared for research-only (non-clinical) purposes (see attached End-User License Agreement) and have the following characteristics:

- The data were recorded from Emergency Department patients in 15 patient care spaces in the "urgent care" areas of an academic, regional referral medical center over a two-year period with funding support from the Agency for Healthcare Research and Quality (AHRQ, grant R18-HS022860). Source patient consent was not obtained,[1] as the study site Institutional Review Board determined that the data acquired represented an anonymized, de-identified version of clinical data that a.) were routinely acquired by standard clinical systems in use and b.) could not be traced back to individual patients.[2]

- The datastream outputs from standard Philips IntelliVue MP30 series bedside patient monitors were recorded continuously and saved in human-/machine-readable format in .json files. The following datastream outputs[3] were recorded for the PERSEUS research program:
  - -Electrocardiogram waveform (single lead EKG, typically lead II) at 250Hz
  - -Pulse oximetry waveform (PPG) at 125Hz
  - -Vital signs numerics
  - -Alarm messages (institution-specified yellow and red alarms and alarm thresholds)
  - -Quality-of-Signal (QoS) values for PPG waveform from experimental UCSF code

- The .json files are organized in folders, each representing a research period month (non-sequential) with subfolders representing research period days (sequential; see FIGURE 1), *e.g.,* YYYYMM month / YYYYMMDD / x00-##.YYYY-MM-DD (file)

- The recorded datastreams (12 months' worth) are being disseminated as 5,475 .json files comprising 1.68Tb, representing ~97.4% of monitor data output for the study period. Each .json file contains the entirety of the research-recorded datastream from one patient monitor over 24 hours, *i.e.,* ~[0000 hours][4] at the head / top of the file to ~[2359 hours] at the end / bottom of the file. Source patient clinical characteristics and correlates were not recorded[1] such that there are no dividers that explicitly separate the datastream segment(s) of one patient from that of an earlier or later patient.

- Due to the experimental, in-development nature of the Medical Technology interface- Open / Research [MeTeOR] software used to record the datastreams, the datastream recordings exhibited brief data packet losses (*i.e.,* ~1 second) as well as intermittent software crashes (with loss of data for the seconds to hours duration between crash and recovery) especially at times of network congestion due to high ED census. The former can be detected as short sub-/second segments of missing signal primarily on the EKG and PPG waveforms; the latter typically manifests as abrupt datastream cessation, often with missing machine-day .json file(s) for subsequent time periods (these gaps in the datastream record are marked by "lost" file placeholders in the file / folder structure).

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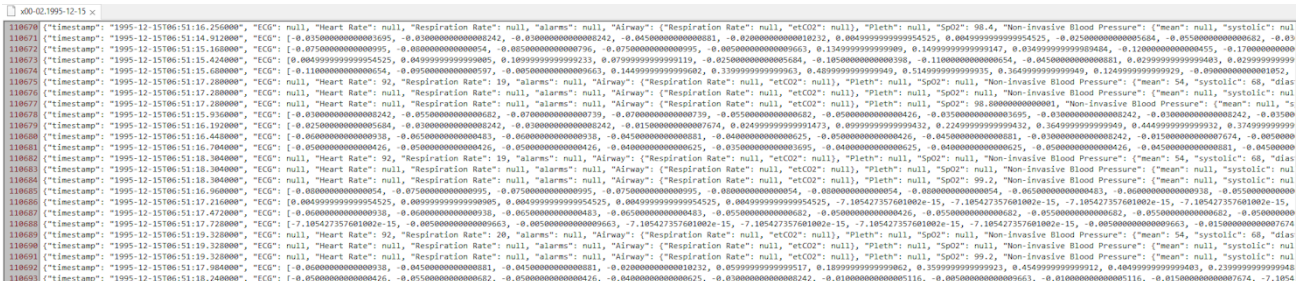
[1] ATOMICS-CC source patients were consented for collection of demographics, and ED and tracer clinical data.

[2] Specifically, all date-/time-stamps and patient care space identifiers have been replaced/obfuscated, and the key file has been irretrievably deleted.

[3] Additional datastream output elements, *e.g.,* ABP, CVP, have been successfully acquired for parallel research.

[4] Several minutes from the preceding day are typically recorded at the head/top of the file.

- Each .json data file (typically) contains 10^5 lines of data in the following format:



- Examples of data lines are as follows (*i.e.,* each timestamped line is a .json object):

Time in YYYY-MM-DDTHH:mm:ss.microseconds000 format

EKG waveform in 64-value arrays for 0.256 seconds, *i.e.,* 250Hz

{"timestamp": "1982-06-25T23:58:18.128000", "ECG": [-0.07500000000000995, -0.0800000000000054, -0.08500000000000796, -0.09500000000000597, -0.09500000000000597, -0.09000000000001052, -0.08500000000000796, -0.08500000000000796, -0.0800000000000054, -0.0800000000000054, -0.07500000000000995, -0.06500000000000483, -0.05500000000000682, -0.03500000000000003695, -0.03500000000000003695, -0.05500000000000682, -0.07500000000000995, -0.03500000000000003695, 0.07499999999999574, 0.19499999999999318, 0.3649999999999949, 0.6299999999999955, 0.914999999999992, 1.0949999999999918, 1.1499999999999915, 1.134999999999991, 1.0699999999999932, 0.9849999999999923, 0.8749999999999929, 0.7499999999999929, 0.5849999999999937, 0.4199999999999946, 0.269999999999996, 0.15999999999998948, 0.06499999999999062, -0.01500000000000764, -0.0800000000000054, -0.13000000000000966, -0.16500000000000625, -0.1950000000000074, -0.22000000000000597, -0.22500000000000853, -0.23000000000000398, -0.23500000000000654, -0.23000000000000398, -0.23000000000000398, -0.22500000000000853, -0.21500000000001052, -0.21000000000000796, -0.21000000000000796, -0.2050000000000054, -0.1950000000000074, -0.1950000000000074, -0.1950000000000074, -0.19000000000000483, -0.19000000000000483, -0.19000000000000483, -0.18500000000000938, -0.18500000000000938, -0.18000000000000682, -0.18000000000000682, -0.17500000000000426, -0.17000000000000088, -0.17000000000000088], "Heart Rate": null, "Respiration Rate": null, "alarms": null, "Airway": {"Respiration Rate": null, "etCO2": null}, "Pleth": [2116, 2119, 2121, 2122, 2122, 2122, 2119, 2112, 2104, 2094, 2087, 2083, 2078, 2076, 2080, 2085, 2088, 2089, 2090, 2090, 2087, 2080, 2072, 2062, 2052, 2042, 2034, 2033, 2035, 2033, 2027, 2018], "SpO2": null, "Non-invasive Blood Pressure": {"mean": null, "systolic": null, "diastolic": null}, "qos": -1}

Numeric vital signs: HR and RR in bpm; SpO2 in %; NIBP in mmHg. "Null" indicates no value on monitor. Airway values indicate EtCO2-based measurements. QoS = Quality of Signal based on UCSF svd-based PPG waveform analysis

PPG waveform in 32-value arrays for 0.256 seconds, *i.e.,* 125Hz

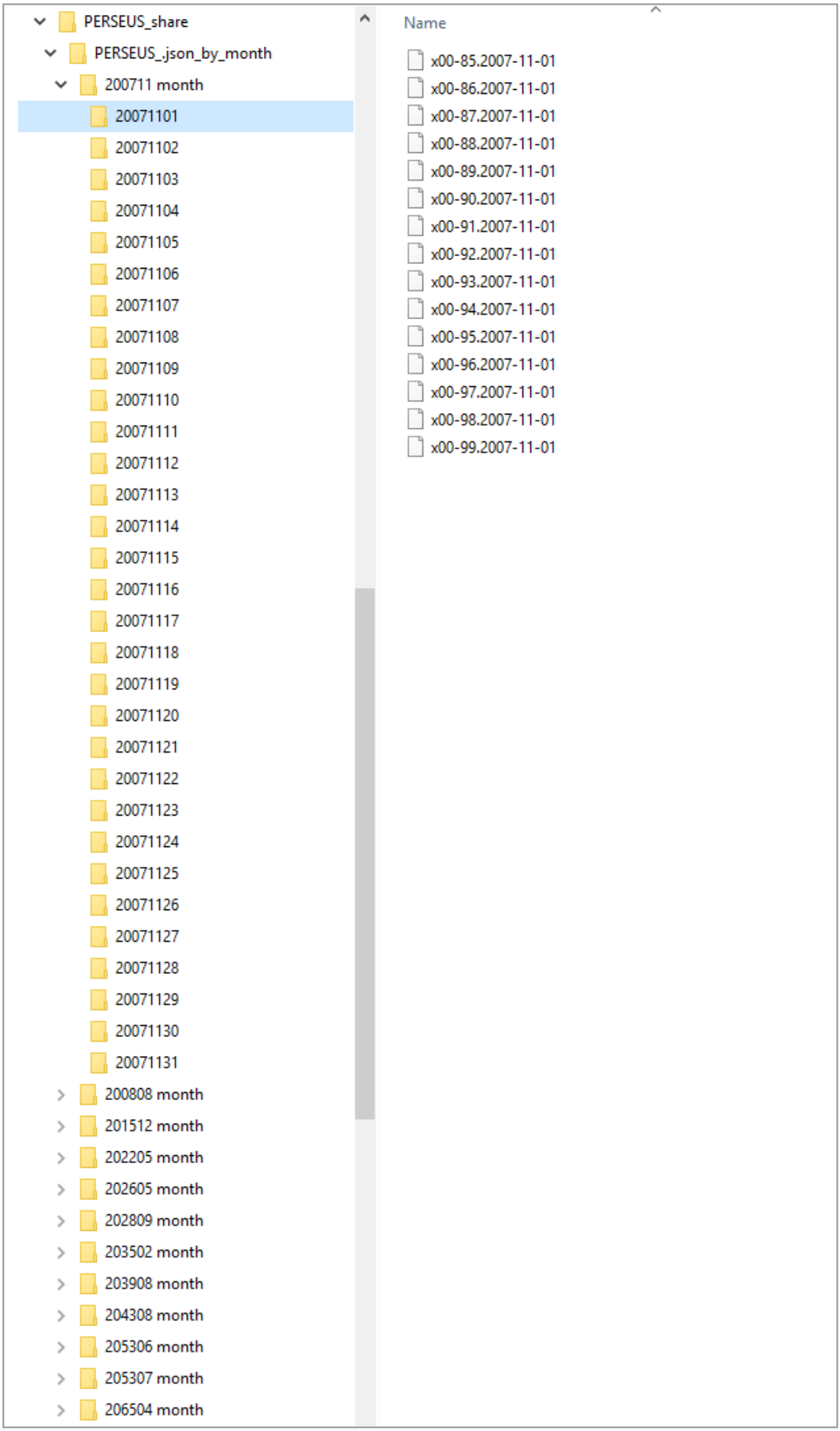
Time in YYYY-MM-DDTHH:mm:ss.microseconds000 format

{"timestamp": "1982-06-25T23:58:18.112000", "ECG": null, "Heart Rate": null, "Respiration Rate": null, "alarms": {"Alarm_P_0": {"source": "NOM_PULS_OXIM_SAT_O2", "state": "AL_LATCHED", "code": "NOM_EVT_LO", "type": "MED_PRI_P_AL", "string": ""}}, "Airway": {"Respiration Rate": null, "etCO2": null}, "Pleth": null, "SpO2": null, "Non-invasive Blood Pressure": {"mean": null, "systolic": null, "diastolic": null}, "qos": 1}

Alarm messages: study-selected yellow and red alarms with alarm source, state, code, type. See *"Data Export Interface Programming Guide; IntelliVue Patient Monitor X2, MP Series, MX Series"* (Philips, 2011; available online) for alarm message details.

- Notes: -An EKG waveform value of -40.96 indicates electrical flatline value
  -A PPG waveform value of 2048 indicates photoplethysmographic flatline value
  -The lines of data are not in precise temporal sequence due to the packeted nature of Philips monitor MIB datastream emissions, *e.g.,* {"timestamp": "1982-06-25T23:58:18.512000", ...} may precede {"timestamp": "1982-06-25T23:58:18.360000", ...} This can be readily corrected with a sort function (Python code provided on request).

FIGURE 1. The PERSEUS full datasets are organized as follows:



ATOMICS data subsets

As part of the full PERSEUS dataset, the Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events [ATOMICS] data subsets feature use-case / application-specific features, as follows:

- ATOMICS-0/-1/-2/-3

Three non-contiguous weeks' worth of recorded monitor datastreams from the full dataset was selected based on completeness and seasonal variation then adjudicated / annotated and processed into the ATOMICS-0/-1/-2/-3 packages in .csv files. These four packages consist of various combinations of peri-alarm or non-alarm datastreams, alarm adjudications, and waveform annotations in a high temporal resolution linear format. Specifically, the timestamps of all individual yellow and red alarms for two weeks' worth of select machine-day .json files were extracted with Splunk v6.3.1 (Splunk, San Francisco, CA) and used to slice out 10-minute data windows surrounding each yellow or red alarm event, *i.e.,* 5 minutes preceding the alarm and 5 minutes after the alarm. Using the research program's Python code for monitor datastream visualization and annotation, the principal investigator[5] visualized these two weeks' worth (ATOMICS-1/-2) of peri-alarm monitor datastreams to adjudicate their clinical significance (significant; not significant; indeterminate) and severity (emergent; urgent; non-urgent; indeterminate). For example, a red alarm featuring clear pulse oximetry signal and oxygen saturation decreasing from 95% to 87% over 20 seconds was adjudicated as a clinically significant, urgent alarm; a ventricular tachycardia red alarm triggered by noisy EKG signal and associated with a clear, stable, and pulsatile pulse oximetry waveform at a normal heart rate was adjudicated as a clinically non-significant, non-urgent alarm. Adjudications were completed with an emphasis on differentiating true positive alarms from false positive alarms. For signals level analysis, EKG and PPG waveforms for all peri-alarm windows in the ATOMICS-0 and ATOMICS-2 dataset were annotated with clinician expert interpretability at ~0.1s resolution. See FIGURES 2 AND 3 for additional details.

- Each data subset has unique characteristics:
  - ATOMICS-0: Control dataset of clinician-adjudicated/-annotated "true negatives" consisting of 300 stable, 10-minute datastream segments without alarm-triggering features [~3,000 datastream minutes over 300 non-alarm segments with EKG and PPG waveform annotations]
  - ATOMICS-1: Derivation data subset with clinician-adjudicated yellow and red alarms [~8,530 datastream minutes over 853 adjudicated yellow and red alarms; no EKG or PPG waveform annotations]
  - ATOMICS-2: Derivation data subset with clinician-adjudicated yellow and red alarms and clinician-annotated waveforms [~12,340 datastream minutes over 1,234 adjudicated yellow and red alarms with EKG and PPG waveform annotations]
  - ATOMICS-3: Training (exploratory) data subset for potential validation testing of experimental algorithms to be derived from ATOMICS-0/-1/-2 [~2,520 datastream monitor-hours; no yellow and red alarm adjudications or EKG or PPG waveform annotations]
- The ATOMICS subset files are organized in folders, each representing a selected research period week with subfolders representing research period days (sequential; see Figure 4):
  e.g., ATOMICS_#_share / week0#_day0#_<type> / x00-##.YYYY-MM-DD (file)

[5] Co-investigator data review is anticipated for expanded adjudications/annotations and inter-rater analyses.

FIGURE 2: Diagram illustrating the PERSEUS research program's bedside clinical informatics (BCI) research pipeline infrastructure with sample data flow from 15 patient monitors to server / storage for adjudication / annotation and experimental applications (see Kobayashi et al. 2018[6] for details).

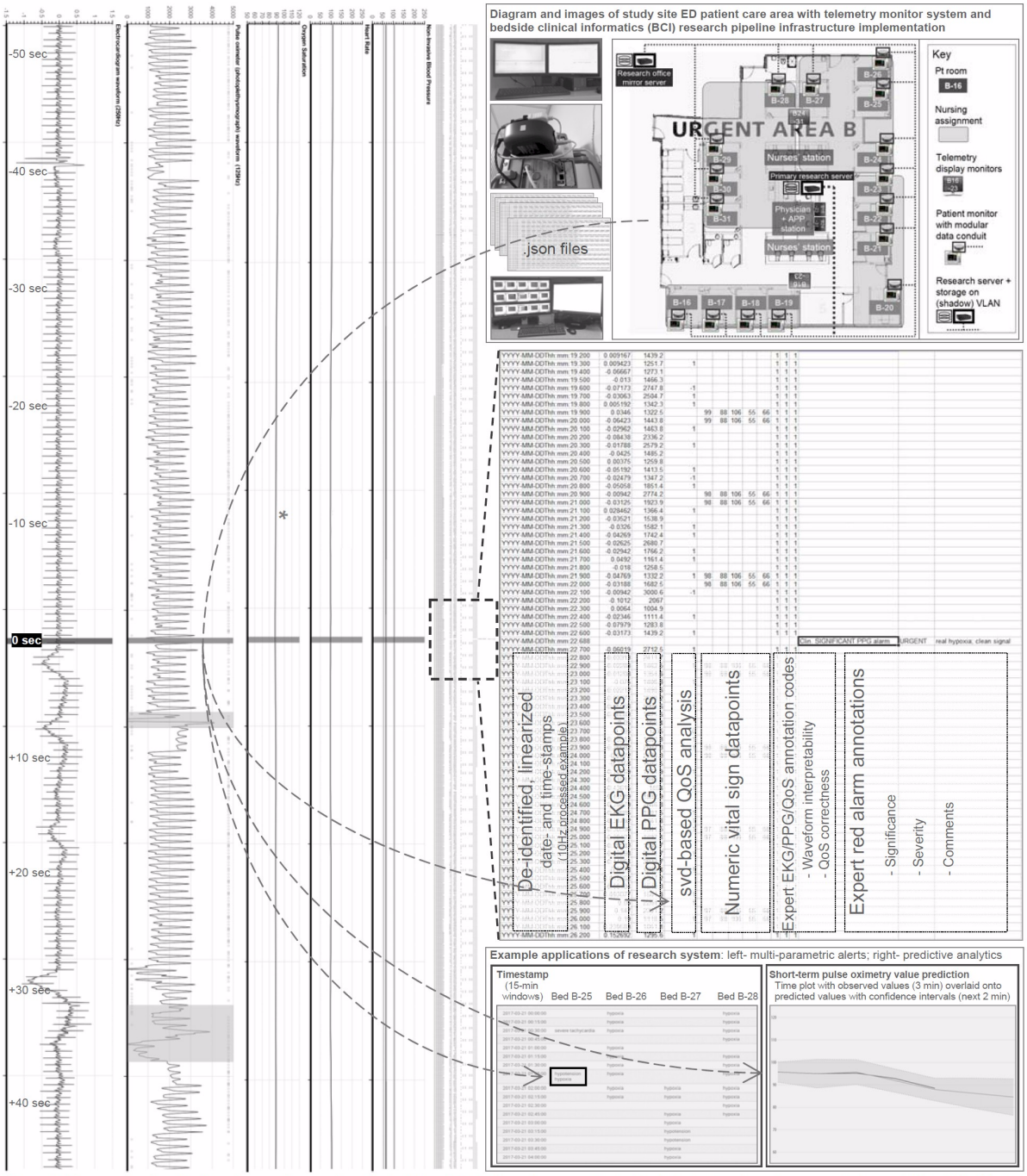


Figure 1. Diagram showing data flow from patient monitor into bedside clinical informatics research pipeline infrastructure through open modular conduit toolkit, with de-identified 100-second sample of an acquired, visualized, and annotated 10-minute data window centered at a true positive hypoxia red alarm (*asterisk indicates patient event with clear pulse oximetry photoplethysmographic signal dropping below 89% oxygen saturation; grey highlight waveform segments indicate expert-annotated non-interpretable signal). The linearized, date-/time-stamped 250Hz single-lead EKG (additional leads optional) and 125Hz pulse oximetry waveform datapoints; svd-based quality of signal (QoS) analysis results; 1Hz numeric vital signs values; alarm information; and expert annotations are stored and exported in human-/machine-readable .json files for experimental development of new monitoring approaches, *e.g.,* multi-parametric alerts and predictive analytics (bottom right insets) for safe and iterative testing in live clinical environments.

[6] Kobayashi L, Oyalowo AC, Agrawal U, Chen S, Asaad W, Hu X, Loparo K, Jay G, Merck DL. Development and deployment of an open, modular, near-real-time patient monitor datastream conduit toolkit to enable healthcare multi-modal data fusion in a live Emergency Department setting for experimental bedside clinical informatics research. *IEEE Sens Lett*, 2019, 3(1): article no. 7101204. https://doi.org/10.1109/LSENS.2018.2880140

FIGURE 3. Diagram representing ATOMICS data subsets relative to full .json dataset.

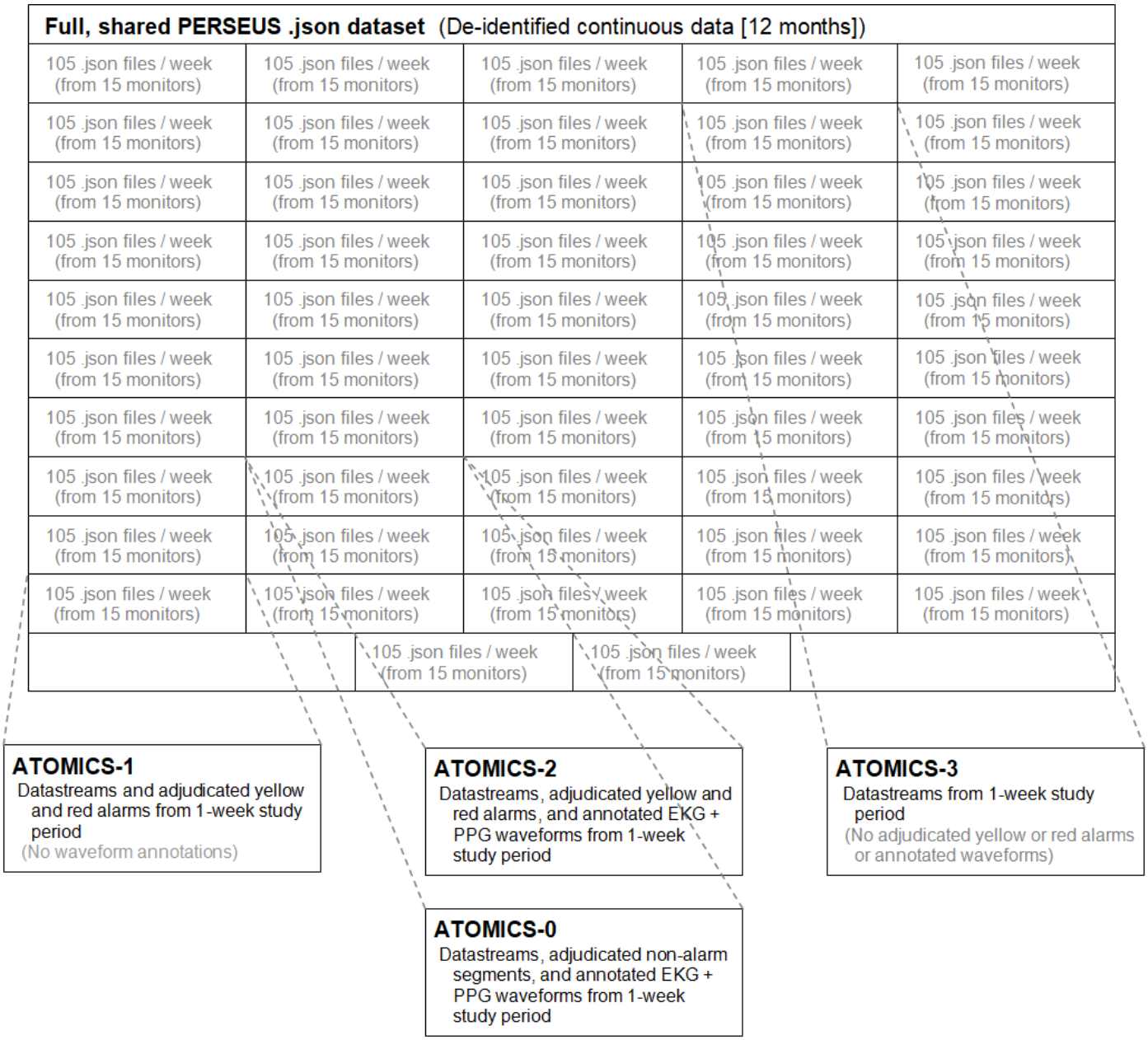
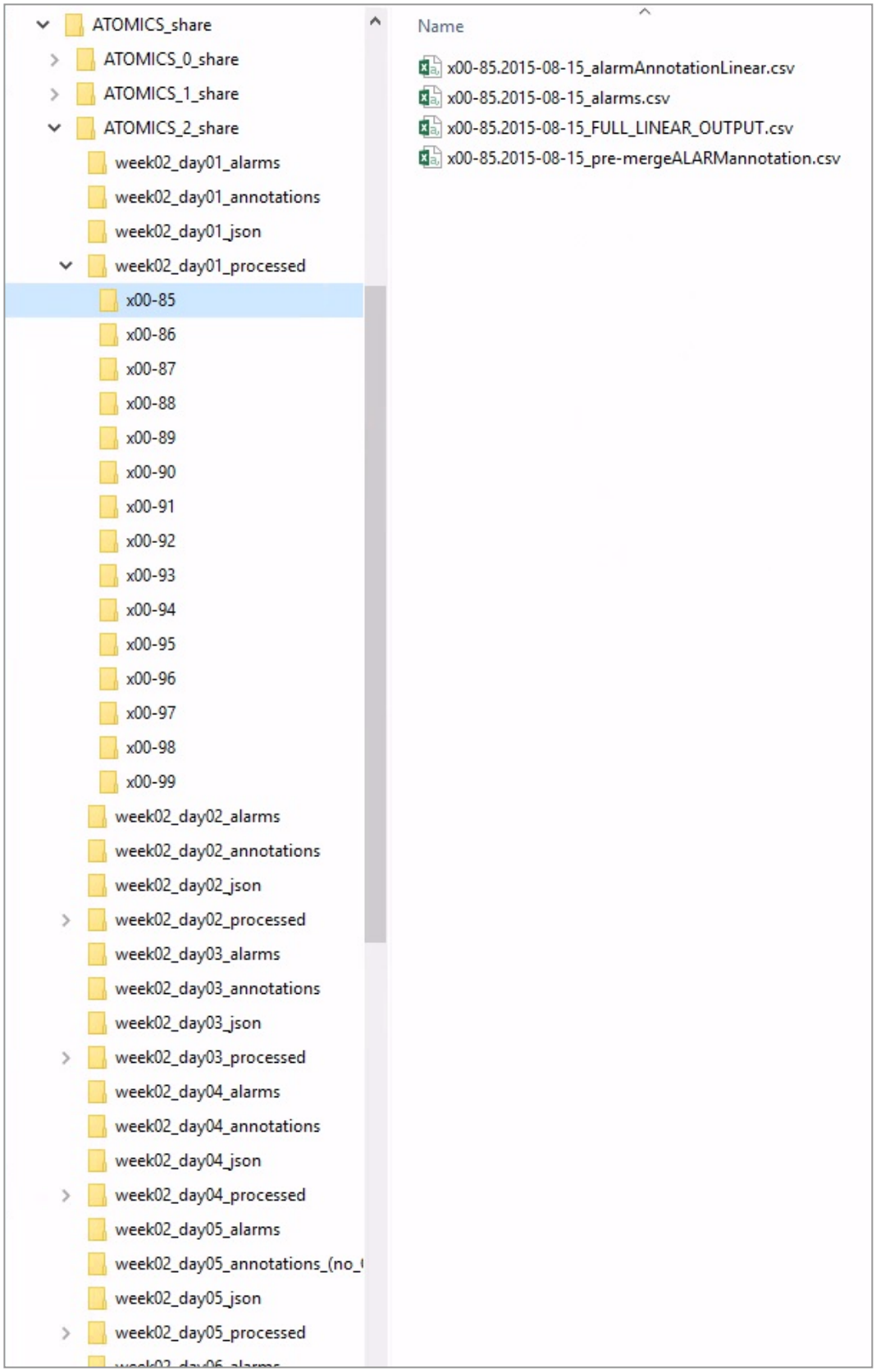


FIGURE 4. The ATOMICS data subsets are organized as follows:



- The process for clinician yellow and red alarm adjudication and waveform annotations was as follows:
  1. Review and adjudicate the alarm based on clinical interpretation of the recorded physiologic waveforms (EKG and/or PPG) and numeric values (HR, RR, SBP / DBP / MAP, SpO2) in the 10-minute datastream window surrounding alarm-triggering event.
     1.1 EKG-based yellow and red alarms:
     Clinical significance:
     -clinically significant (improvement or deterioration)
     -no clinical significance
     -indeterminate clinical significance
     Clinical severity:
     -emergent
     -urgent
     -non-urgent
     -indeterminate

     1.2 PPG / SpO2-based yellow and red alarms:
     Clinical significance:
     -clinically significant (improvement or deterioration)
     -no clinical significance
     -indeterminate clinical significance
     Clinical severity:
     -emergent
     -urgent
     -non-urgent
     -indeterminate

     1.3 BP-based yellow and red alarms:
     Clinical significance:
     -clinically significant (improvement or deterioration)
     -no clinical significance
     -indeterminate clinical significance
     Clinical severity:
     -emergent
     -urgent
     -non-urgent
     -indeterminate

  2. Review and annotate the recorded physiologic waveforms (EKG and/or PPG) for the 10-minute datastream window surrounding the alarm-triggering event.
     2.1 EKG waveform:
     -interpretable (not excessively noisy, recognizable signal in waveforms)
     -not interpretable (noisy or other)
     -off (no signal)

     2.2 PPG waveform:
     -interpretable (not excessively noisy, recognizable signal in waveforms)
     -not interpretable (noisy or other)
     -off (no signal)

- The adjudication and annotation process generated the following outputs:

  - *Yellow and red alarm adjudications*
    Each data line in an alarm annotation file has an alarm event timestamp with a specific adjudication of the alarm's clinical significance and severity along with comments:

    -In x00-##.YYYY-MM-DD_alarmAnnotation.txt files:
      -Alarm significance annotations:
        Clin. SIGNIFICANT
        Clin. INDETERMINATE
        Clin. NOT SIGNIFICANT

      -Alarm severity annotations:
        EMERGENT
        URGENT
        NON-URGENT
        INDETERMINATE

      -Example:
        1982-06-25T05:28:27.088,Clin. SIGNIFICANT PPG alarm,URGENT,
        1982-06-25T14:24:02.256,Clin. SIGNIFICANT EKG alarm,URGENT,
        1982-06-25T20:55:49.960,Clin. INDETERMINATE EKG alarm,INDETERMINATE,

  - *Signals-level annotations (EKG and PPG)*
    Each data line in an EKG or PPG annotation file has start and end timestamps that define a temporal window with a specific clinician annotation:

    -In x00-##.YYYY-MM-DD_ekgAnnotation.txt files:
      -EKG window annotations:
        EKG INTERPRETABLE
        EKG NOT INTERPRETABLE [7]
        EKG OFF

      -Example:
        1982-06-25T20:55:23.459,2017-05-25T20:55:28.747,EKG INTERPRETABLE
        1982-06-25T20:55:30.193,2017-05-25T20:55:34.215,EKG INTERPRETABLE
        1982-06-25T20:54:35.417,2017-05-25T20:54:39.936,EKG OFF

    - In x00-##.YYYY-MM-DD_ppgAnnotation.txt files:
      -PPG window annotations:
        PPG INTERPRETABLE
        PPG NOT INTERPRETABLE [5]
        PPG OFF
      -QoS window annotations (experimental bedside processing; ignore)

      -Example:
        1982-06-25T05:24:02.230,2017-05-25T05:24:08.811,PPG INTERPRETABLE,QoS NOT Correct
        1982-06-25T05:27:41.538,2017-05-25T05:27:47.322,PPG INTERPRETABLE,QoS CORRECT
        1982-06-25T05:27:36.069,2017-05-25T05:27:38.871,PPG OFF,QoS CORRECT

[7] Datastreams not annotated as INTERPRETABLE or OFF were back-populated as NOT INITERPRETABLE.

- Additional processing of the data in source .json, annotations .txt, and alarms .csv data files generated four grouped file types:

  - AlarmAnnotationLinear .csv files, *i.e.,* x00-##.YYYY-MM-DD_alarmAnnotationLinear.csv, contain re-formatted annotation data for additional processing.

  - Alarms .csv files, *i.e.,* x00-##.YYYY-MM-DD_alarms.csv, contain all the high priority EKG, PPG / SpO2, and BP time-stamped yellow and red alarms of clinical interest for the PERSEUS research program.

    -Example:

_time	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(ala	values(duration)
2011-07-25T05:28:27.088-0400												hypoxia		10.24
2011-07-25T05:28:38.352-0400													hypoxia	52.224
2011-07-25T05:29:32.624-0400												hypoxia		5.12
2011-07-25T09:52:54.992-0400					tachycardia									55.296
2011-07-25T09:53:51.312-0400		sev.tachycardia												112.64
2011-07-25T09:58:10.384-0400		sev.tachycardia												9.248
2011-07-25T10:00:32.720-0400					tachycardia									21.536
2011-07-25T10:00:55.248-0400		sev.tachycardia												342.016

  - Full Linear Output .csv files, *i.e.,* x00-##.YYYY-MM-DD_FULL_LINEAR_OUTPUT.csv, contain the re-formatted compilation of alarm, datastream, and adjudication / annotation data for additional processing.

  - Pre-merge Alarm Annotation .csv files, *i.e.,* x00-##.YYYY-MM-DD_pre-mergeALARMannotation.csv, contain re-formatted data for additional processing.

- End-users will need to access and manipulate these file groups (four files per machine-day) with the research program's III-ATOMICS_dataset_window_processor.py code (or III-ATOMICS_dataset_window_processorSLC.py code for ATOMICS-0)– this last step allows the processing and re-packaging of all relevant data in fully-populated, sorted, linearized format into individual .csv files for each yellow and red alarm at a user-specified data resolution (using mean, median, or other [*i.e.,* user-coded] processing), *e.g.,* x00-##.YYYY-MM-DD_alarm_001_FINAL_window_10Hz_MEAN.csv See instructions / comments in code for additional details.

  - Notes: -Depending on the specific ATOMICS data subset, there may or may not be annotations for EKG, PPG, and/or QoS; please see TABLES 1A AND 1B below.

    -ATOMICS-0 differs from ATOMICS-1/-2/-3 in that it consists of a data *sub*subset derived from ATOMICS-2. In order to efficiently create a control data subset of true negative datastream windows without alarm-triggering events, investigators used "latched" yellow and red alarms[8] to identify monitor datastream windows with physiologic signals but without alarm-triggering events. With investigator / clinician review of the 10-min datastream windows surrounding these latched non-triggered alarms, 300 select latched controls (SLC) were identified and processed. For each of these SLCs, the x00-##.YYYY-MM-DD_alarmAnnotationSLC.txt files contain data lines with the following information in the comments:

      Waveform: P = PPG, E = EKG

      Quality of signal: + (good), 0 (absent), - (poor); > (progression)

    e.g., a control datastream window with good PPG and loss of EKG would be:

      1982-06-25T17:26:23.952-0400,Clin. NOT SIGNIFICANT PPG alarm,NON-URGENT,latched alarm; +P+>0E

[8] A latched alarm was defined for dataset purposes as a residual alarm which had been triggered by a preceding alarm-triggering event and which had not been silenced, such that the latched alarm did not correspond to an alarm-triggering event in the concurrent datastream window. For example, a hypoxia alarm set off at 1982-06-25T18:20:59.970 could re-appear in the research system as a latched alarm at 1982-06-25T18:27:33.789 without an alarm-triggering change in datastream.

- The PERSEUS dissemination package contains Python code that will enable one approach to start processing the ATOMICS dataset. See below for use instructions for the included III-ATOMICS_dataset_window_processor.py code that will process the datasets with a mean or median function at user-specified window sizes in preparation for further manipulation and analysis.

  -The code is written for Python 2.7 in Microsoft Windows environments; any Python IDE / interpreter (*e.g.,* Anaconda, PyCharm) will be able to run the code with the following dependencies:

    -os
    -csv
    -numpy
    -pandas
    -time

  -Transfer the III-ATOMICS_dataset_window_processor.py file into a new folder along with the 4 files in the machine-day file group to be processed, *i.e.,*

    x00-##.YYYY-MM-DD_alarmAnnotationLinear.csv
    x00-##.YYYY-MM-DD_alarms.csv
    x00-##.YYYY-MM-DD_FULL_LINEAR_OUTPUT.csv
    x00-##.YYYY-MM-DD_pre-mergeALARMannotation.csv

  -Start the code; the following text-based interface should appear:

```
Connected to pydev debugger (build 181.4203.547)

*** CLEAR OUT ALL / ANY PREVIOUS "ALARM WINDOW", "MEAN(TEMP)", AND "MEDIAN" CSV FILES BEFORE RUNNING WINDOW PROCESSOR ***

*** THIS CODE NEEDS THE FOLLOWING FILES FOR WINDOW PROCESSING ***

     x00-##.YYYY-W#-D#_FULL_LINEAR_OUTPUT.csv
     x00-##.YYYY-W#-D#_alarmAnnotationLinear.csv
     x00-##.YYYY-W#-D#_pre-mergeALARMannotation.csv


Enter DATE of ATOMICS dataset file to window and process [e.g., "YYYY-MM-DD", incl. quotes]: "2015-08-15"
Enter NAME of machine of ATOMICS dataset file to window and process [e.g., "95", incl. quotes]: "85"
Enter processing window in seconds [greater than 0.004;  NB: annotations at max 0.1sec]: 0.5
Enter processing function ["mean" or "median", incl. quotes]: "mean"
```

  -Enter the date of the machine-day file group to be processed (with quotes[9]), *e.g.,* "2015-08-15" for file group x00-85.2015-08-15_...

  -Enter the machine number of the machine-day file group to be processed (with quotes), *e.g.,* "85" for file group x00-85.2015-08-15_...

  -Enter the time window to be used for processing (greater than 0.004 seconds), *e.g.,* 0.5 (this will process the dataset into linearized 0.5 second entries, *i.e.,* 2Hz)

  -Enter the processing function to be used for processing (with quotes), *e.g.,* "mean" (this will process the dataset into linearized 0.5 second entries that represent the mean datastream values for the specified processing time window)

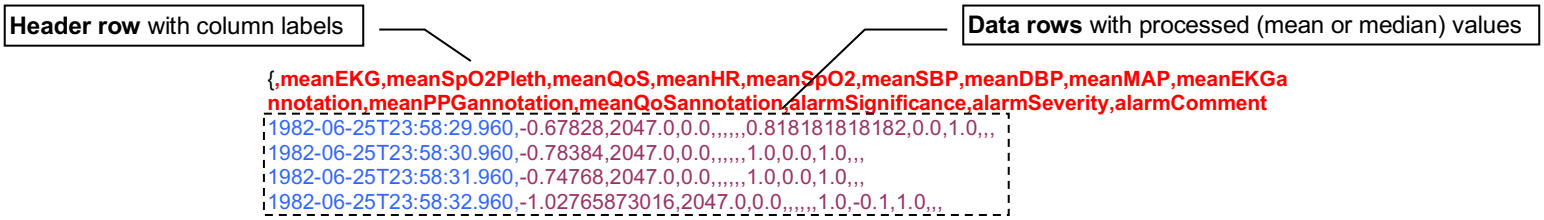
[9] The need for quotes is a result of the use of Python 2.7 input instead of raw_input.

-The code may take up to 20-30 minutes or more depending on the file group's file sizes and processing time window specified. Upon completion, the output files will appear in the same folder:

x00-##.YYYY-MM-DD_alarm_***_FINAL_window_@@@Hz_001.csv
x00-##.YYYY-MM-DD_alarm_***_FINAL_window_@@@Hz_002.csv
x00-##.YYYY-MM-DD_alarm_***_FINAL_window_@@@Hz_003.csv
...
x00-##.YYYY-MM-DD_alarm_***_FINAL_window_@@@Hz_###.csv

<***> = mean or median <@@@> = frequency in Hz

-Each output .csv data file will contains several 10^2 to 10^5 lines of data (depending on temporal resolution selected) in the following format, example at 1Hz:



- ATOMICS-CC

The PERSEUS research program acquired ED bedside patient monitor datastreams continuously from the study area and displayed specific elements on a remote-mirroring dashboard display in the ED research office. Research assistants used this setup to screen for potential subjects based on whether they met inclusion criteria, as follows:

1. A patient who triggered any of the study-selected, standard red alarms on a patient monitor (based on manufacturer algorithms and institutional configuration) was enrolled into the single parameter alarm [SPA] group: asystole, ventricular fibrillation, ventricular tachycardia; bradycardia (HR < 50 bpm), tachycardia (HR > 120 bpm); hypotension (SBP < 90 mmHg), hypertension (SBP > 200 mmHg); hypoxia (SpO2 < 89%).[10]
2. A patient who triggered two or more standard SPAs that all occurred within a 15-minute "concurrence" window was enrolled into the experimental multi-parametric alert [MPA] group, *e.g.,* tachycardia alarm for HR 135 bpm at 02:51:48 and hypotension alarm for BP 78/50 mmHg at 02:57:33. The specific window length was selected to a.) focus on the temporal proximity of discrete vital sign abnormalities as a reflection of severe underlying pathology impacting interconnected cardiopulmonary systems, and b.) reduce the likelihood of queries detecting overlapping alarms that were set off by two different patients during a rapid ED room turnover.
3. A patient who did not trigger any of the standard, study-selected red alarms was enrolled into the no alarm [NA] group (with checks of the electronic medical record to additionally confirm the absence of alarm triggering vital signs during their ED care, in case of non-monitored patient, undetected failure of datastream or research pipeline infrastructure).

Eligible patients were matched and recruited into [MPA]-[SPA]-[NA] triads in a 1:1:1 ratio in order to conduct controlled comparative analyses of the two monitoring approaches. For example, if one patient set off an MPA, s/he was used to start a new subject triad, into

[10] Apnea (RR) alarms had been institutionally de-activated at the study site ED.

which an SPA subject and a NA subject were subsequently enrolled after matching by age (10-year range), sex, Emergency Severity Index (ESI), and chief complaint category. Each potential subject was approached by a research assistant for informed consent to follow their clinical course via in-network hospital medical records over a 3-month tracer period. Pre-specified primary endpoints included death, severe cardiopulmonary events (*e.g.,* administration of BLS, ALS, ACLS; cardiac arrest), malignant arrhythmias, symptomatic / stable arrhythmias, emergent life-saving procedures (*e.g.,* coronary intervention; AICD or pacer insertion), respiratory / ventilatory support (BiPAP, invasive mechanical ventilation), and escalation in care unit requirement, as set forth by Utstein Style and similar standardized reporting guidelines.[11] Secondary endpoints included other significant interventions for life- / limb-threatening conditions and admission / re-admission for related conditions.

Deriving from these efforts, the ATOMICS Clinical Correlate (ATOMICS-CC) package consists of de-identified, date-obfuscated, consented patient subjects' demographic information, triage vital signs, in-ED clinical correlates / dispositions / diagnoses; base monitoring system red alarm information; and subsequent 3-month in-network chart review data along with the excerpted .json monitor datastream record for the durations of patients' stays in ED urgent care study areas. This was intended to help create and disseminate an ED-specific patient [demographic-datastream-outcomes] dataset for collaborative offline analyses. For example, investigators are analyzing the PPG / SpO2 waveform for the 15 seconds preceding hypoxia red alarm for any subject who triggered an MPA with hypoxia component.

Citation List for Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events [ATOMICS]

- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Push Electronic Relay for Smart Alarms for End User Situational Awareness (PERSEUS) research program full original .json files dataset. Brown Digital Repository, 2018. Available at: https://doi.org/10.26300/1t2a-qm27

- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events-0 (ATOMICS-0) dataset. Brown Digital Repository, 2018. Available at: https://doi.org/10.26300/17cn-bt67

- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events-1 (ATOMICS-1) dataset. Brown Digital Repository, 2018. Available at: https://doi.org/10.26300/ck2t-be58

- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events-2 (ATOMICS-2) dataset. Brown Digital Repository, 2018. Available at: https://doi.org/10.26300/m554-d248

[11] Perkins GD, Jacobs IG, Nadkarni VM, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: Update of the Utstein resuscitation registry templates for out-of-hospital cardiac arrest. *Circulation* 2015 Sep;132(13):1286-300. PMID: 25391522

- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events-3 (ATOMICS-3) dataset. Brown Digital Repository, 2018. Available at: https://doi.org/10.26300/0dtq-hf36
- Kobayashi L, Oyalowo A, Agrawal U, Hu X, Loparo KA, Leary OP, Jay GD, Merck DL. Adjudicated / Annotated Telemetry signals for Medically Important and Clinically Significant events-CC (ATOMICS-CC) dataset. Brown Digital Repository, 2019. Available at: https://doi.org/10.26300/m9pp-4m49

Programming source code / compiled code for open dissemination in preparation

- Kobayashi L, Oyalowo A, Agrawal U, Asaad W, Hu X, Loparo KA, Jay GD, Merck DL. Medical Technology interface- Open / Research (MeTeOR) toolkit. In preparation for dissemination, Brown Digital Repository.

TABLE 1A. ATOMICS Data Subset Descriptions (1 of 2)

Data Subset	Intended Application	Data Subset De-identified?	Datastream Source Pool	Datastream Window	Peri-alarm Monitor Datastreams Included			
					1-lead EKG (250Hz) and pulse oximetry PPG (125Hz) waveforms	Numeric vital signs (1Hz)	Alarms extracted (select alarms only)	UCSF svd-based Quality of Signal (QoS) (variable frequency)
ATOMICS-0	Training (control data subset)	yes	15 ED beds * 7 days	-5min <- alarm -> +5min	yes	yes	no	yes
ATOMICS-1	Training (derivation data subset)	yes	15 ED beds * 7 days	-5min <- alarm -> +5min	yes	yes	yes	yes
ATOMICS-2	Training (derivation data subset)	yes	15 ED beds * 7 days	-5min <- alarm -> +5min	yes	yes	yes	yes
ATOMICS-3	Training (exploratory data subset)	yes	15 ED beds * 7 days	-5min <- alarm -> +5min	yes	yes	no	yes
ATOMICS-CC	Testing (clinical correlate data subset)	yes	15 ED beds * 640 days	ED urg. area stay duration	yes	yes	yes	yes
Source .json	Testing (original full dataset)	yes	15 ED beds * 365 days	n/a	all	all	no	all

TABLE 1B. ATOMICS Data Subset Descriptions (2 of 2)

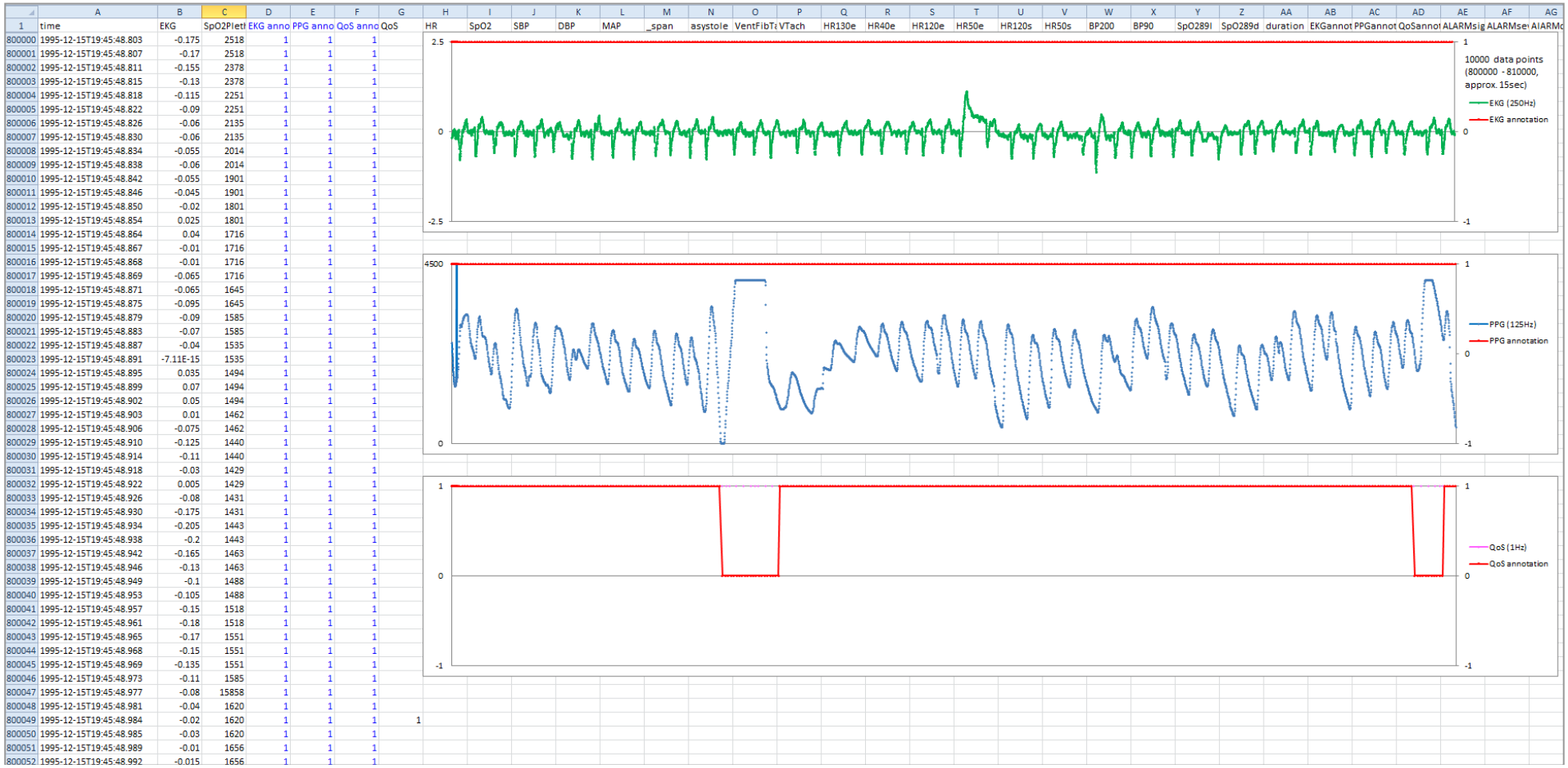
Data Subset	Adjudications / Annotations Included				Total alarms^	Alarms by monitor modality (incl. duplicate and possibly latched alarms)			Clinically *significant* alarms			Clinically *non-significant* alarms			Clinically *indeterminate* alarms		
	EKG waveform annotation	PPG waveform annotation	QoS correctness adjudication	Alarm adjudications		EKG	PPG	BP	EKG	PPG	BP	EKG	PPG	BP	EKG	PPG	BP
ATOMICS-0	no	no	no	yes (true negative controls[#])	**300**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ATOMICS-1	no	no	no	yes (true positives; true negatives; indeterminates)	**853**	365	388	100	263	83	93	93	117	4	9	188	3
ATOMICS-2	yes	yes	3 of 7 days	yes (true positives; true negatives; indeterminates)	**1,234**	671	430	133	550	84	126	92	190	2	29	156	5
ATOMICS-3	no	no	no	no	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ATOMICS-CC	no	no	no	yes (true positives; true negatives; indeterminates)	**1,252** (red only)	494	633	125	291	243	115	144	94	6	59	296	4
Source .json	no	no	no	no	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[#] no alarm-generating waveform or vital signs

^ Alarms included (nb: ATOMICS-CC only contains red alarms **[bold]**) :

Asystole
VTach/VFib
Severe tachycardia (HR ≥ 130bpm); Tachycardia (HR ≥ 120bpm)
Severe bradycardia (HR ≤ 40bpm); Bradycardia (HR ≤ 50bpm)
Hypoxia (SpO2 ≤ 89%)
Hypertension (SBP ≥ 200mmHg)
Hypotension (SBP ≤ 90mmHg)

FIGURE 5. Sample excerpt of post-processed, linearized, adjudicated / annotated ATOMICS data (de-identified) as imported into Excel for demonstration purposes. The human-/machine-readable data in the research program's open dissemination packages can be readily accessed and studied with available analytics software. The left columns contain post-processed data; the right top, middle, and bottom panels display original single-lead EKG waveform (250Hz); pulse oximetry waveform (125Hz); and UCSF svd-based bedside pulse oximetry quality-of-signal (QoS) analysis output (+1 = good QoS; 0 = indeterminate QoS; -1 = poor QoS), respectively. The solid lines in the top two panels indicate investigator clinician annotation of waveform quality (+1 = interpretable signal; 0 = no signal; -1 = non-interpretable signal).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	time	EKG	SpO2Plet	EKG anno	PPG anno	QoS anno	QoS	HR	SpO2	SBP	DBP	MAP	_span	asystole	VentFibT	VTach	HR130e	HR40e	HR120e	HR50e	HR120s	HR50s	BP200	BP90	SpO289l	SpO289d	duration	EKGannot	PPGannot	QoSannot	ALARMsig	ALARMse	AlARMc
800000	1995-12-15T19:45:48.803	-0.175	2518	1	1	1																											
800001	1995-12-15T19:45:48.807	-0.17	2518	1	1	1																											
800002	1995-12-15T19:45:48.811	-0.155	2378	1	1	1																											
800003	1995-12-15T19:45:48.815	-0.13	2378	1	1	1																											
800004	1995-12-15T19:45:48.818	-0.115	2251	1	1	1																											
800005	1995-12-15T19:45:48.822	-0.09	2251	1	1	1																											
800006	1995-12-15T19:45:48.826	-0.06	2135	1	1	1																											
800007	1995-12-15T19:45:48.830	-0.06	2135	1	1	1																											
800008	1995-12-15T19:45:48.834	-0.055	2014	1	1	1																											
800009	1995-12-15T19:45:48.838	-0.06	2014	1	1	1																											
800010	1995-12-15T19:45:48.842	-0.055	1901	1	1	1																											
800011	1995-12-15T19:45:48.846	-0.045	1901	1	1	1																											
800012	1995-12-15T19:45:48.850	-0.02	1801	1	1	1																											
800013	1995-12-15T19:45:48.854	0.025	1801	1	1	1																											
800014	1995-12-15T19:45:48.864	0.04	1716	1	1	1																											
800015	1995-12-15T19:45:48.867	-0.01	1716	1	1	1																											
800016	1995-12-15T19:45:48.868	-0.01	1716	1	1	1																											
800017	1995-12-15T19:45:48.869	-0.065	1716	1	1	1																											
800018	1995-12-15T19:45:48.871	-0.065	1645	1	1	1																											
800019	1995-12-15T19:45:48.875	-0.095	1645	1	1	1																											
800020	1995-12-15T19:45:48.879	-0.09	1585	1	1	1																											
800021	1995-12-15T19:45:48.883	-0.07	1585	1	1	1																											
800022	1995-12-15T19:45:48.887	-0.04	1535	1	1	1																											
800023	1995-12-15T19:45:48.891	-7.11E-15	1535	1	1	1																											
800024	1995-12-15T19:45:48.895	0.035	1494	1	1	1																											
800025	1995-12-15T19:45:48.899	0.07	1494	1	1	1																											
800026	1995-12-15T19:45:48.902	0.05	1494	1	1	1																											
800027	1995-12-15T19:45:48.903	0.01	1462	1	1	1																											
800028	1995-12-15T19:45:48.906	-0.075	1462	1	1	1																											
800029	1995-12-15T19:45:48.910	-0.125	1440	1	1	1																											
800030	1995-12-15T19:45:48.914	-0.11	1440	1	1	1																											
800031	1995-12-15T19:45:48.918	-0.03	1429	1	1	1																											
800032	1995-12-15T19:45:48.922	0.005	1429	1	1	1																											
800033	1995-12-15T19:45:48.926	-0.08	1431	1	1	1																											
800034	1995-12-15T19:45:48.930	-0.175	1431	1	1	1																											
800035	1995-12-15T19:45:48.934	-0.205	1443	1	1	1																											
800036	1995-12-15T19:45:48.938	-0.2	1443	1	1	1																											
800037	1995-12-15T19:45:48.942	-0.165	1463	1	1	1																											
800038	1995-12-15T19:45:48.946	-0.13	1463	1	1	1																											
800039	1995-12-15T19:45:48.949	-0.1	1488	1	1	1																											
800040	1995-12-15T19:45:48.953	-0.105	1488	1	1	1																											
800041	1995-12-15T19:45:48.957	-0.15	1518	1	1	1																											
800042	1995-12-15T19:45:48.961	-0.18	1518	1	1	1																											
800043	1995-12-15T19:45:48.965	-0.17	1551	1	1	1																											
800044	1995-12-15T19:45:48.968	-0.15	1551	1	1	1																											
800045	1995-12-15T19:45:48.969	-0.135	1551	1	1	1																											
800046	1995-12-15T19:45:48.973	-0.11	1585	1	1	1																											
800047	1995-12-15T19:45:48.977	-0.08	15858	1	1	1																											
800048	1995-12-15T19:45:48.981	-0.04	1620	1	1	1																											
800049	1995-12-15T19:45:48.984	-0.02	1620	1	1	1	1																											
800050	1995-12-15T19:45:48.985	-0.03	1620	1	1	1																											
800051	1995-12-15T19:45:48.989	-0.01	1656	1	1	1																											
800052	1995-12-15T19:45:48.992	-0.015	1656	1	1	1																											