The Lifecycle of EEG Data

Acquisition, Analysis and Future Prospects

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Goals

BRIEFLY DISCUSS A VARIETY OF EEG USE-CASES

SUMMARIZE DATA TYPES STORED DURING AND AFTER EEG STUDIES

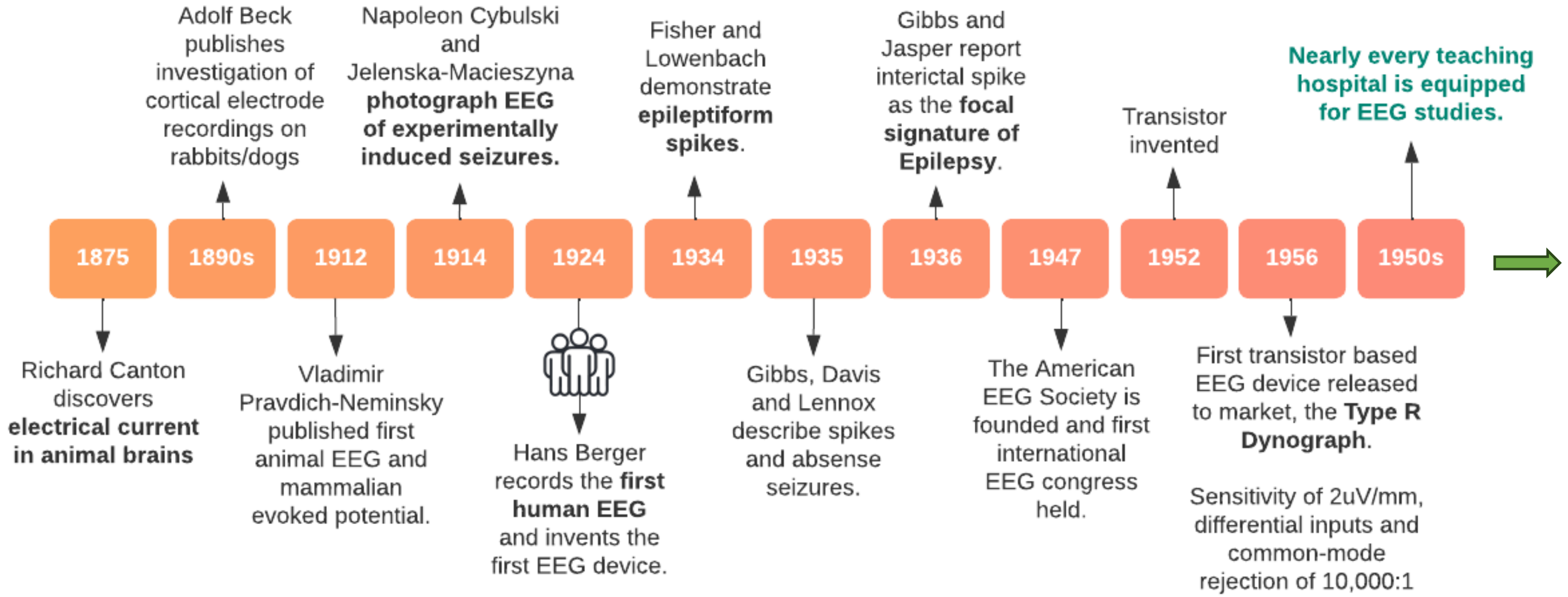
SUMMARIZE THE LIFECYCLE OF EEG DATA

DISCUSS RESEARCH ENABLEMENT, SDK OFFERINGS AND FUTURE DIRECTIONS

Introduction: The Reasons for EEG

- **Monitoring seizures and/or Epilepsy**
- Altered Mental Status
- Evaluation of neurological disorders
- Sleep Disorders
- Traumatic Brain Injury
- Evaluation of psychiatric disorders
- Stroke and vascular disorders
- Surgical resection planning
- Closed-loop stimulation treatment applications
- Evaluation of developmental disorders
- Research studies
- Consumer-grade applications
- A growing list…

Introduction: Early Adoption of EEG



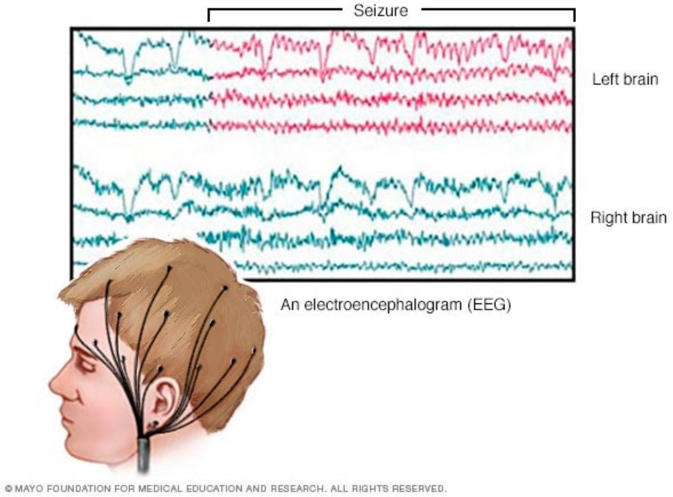
Major academic hospitals are equipped for EEG by the mid-1950s[7]

Introduction: Types of EEG

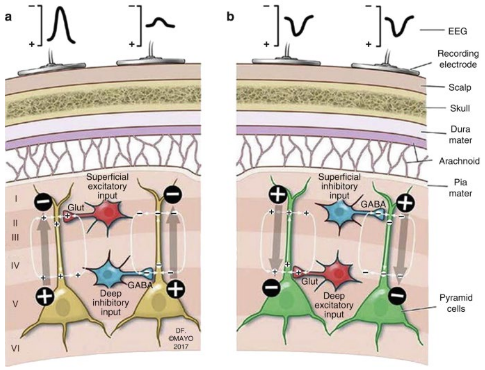
*An electroencephalogram (EEG) is a test that **measures electrical activity** in the brain using small, metal discs (**electrodes**) attached to the scalp. Brain cells communicate via electrical impulses and are active all the time, even during asleep. This activity **shows up as wavy lines on an EEG recording**[1]*

EEG can be collected:

- **On the scalp**
- On the cortical surface
- Beneath the cortical surface



Scalp EEG [1]



Scalp EEG Anatomy [2]

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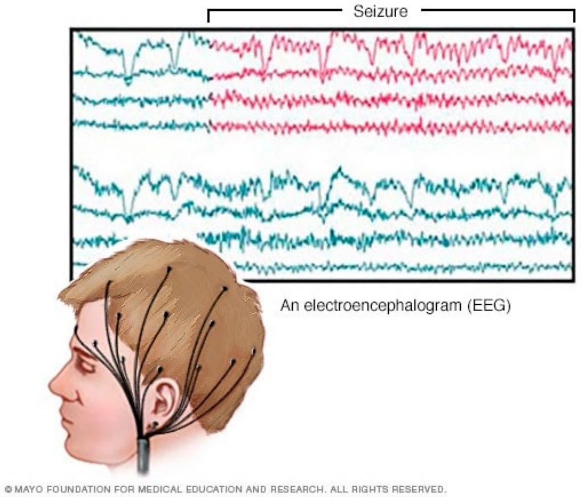

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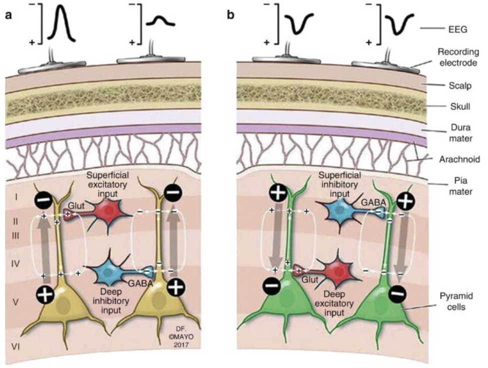

Scalp EEG Anatomy [2]

- Gold cup electrodes + conductive paste are gold standard
- Signal attenuated by scalp, skull, dura, etc. layers
- Localization difficult but broadly feasible
- Artifacts common during wakeful studies

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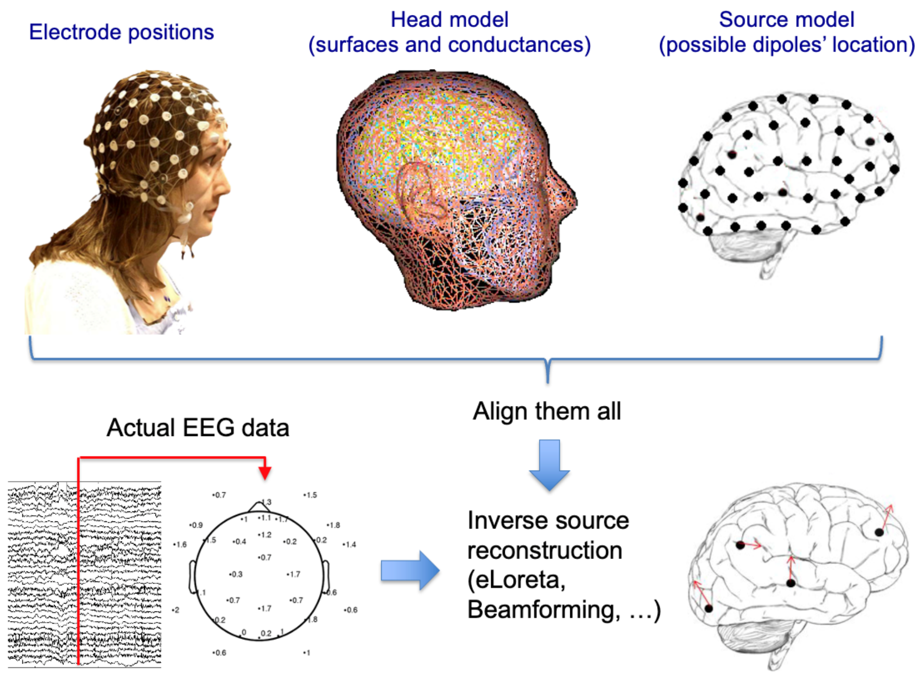

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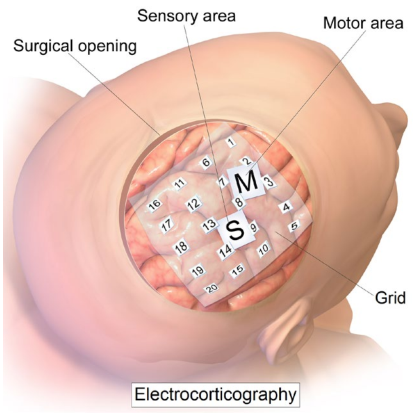
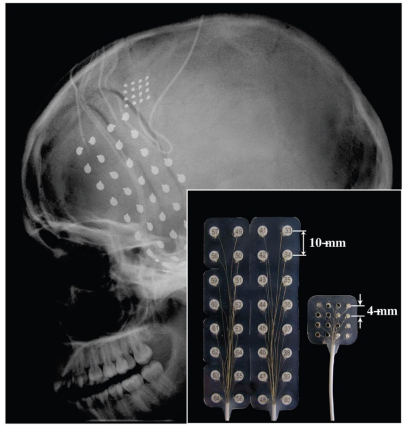


Electrocorticography [3]



Grid, Strip [4]

- *Circular electrodes, 2-3mm diameter, 5-10mm spacing*
- *High spatial and temporal resolution*
- *Less susceptible to artifacts than scalp*
- *Requires full craniotomy for grid/strip placement*

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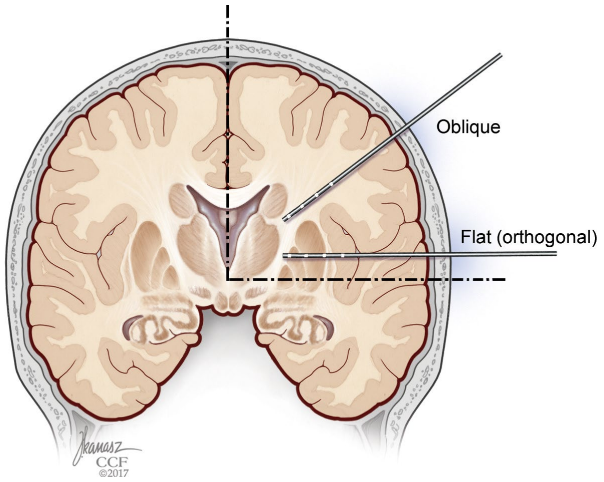
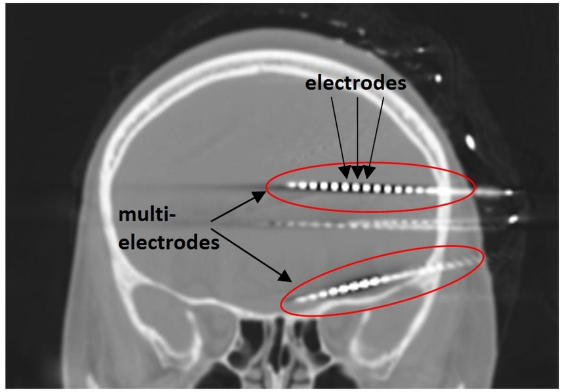


Stereotactic EEG Depth Electrodes [5]



CT of SEEG Depth Electrodes [6]

- *8-16 contacts per electrode, 3.5mm spacing*
- *High spatial and temporal resolution*
- Simultaneous cortical + sub-cortical recording
- Burr holes rather than full craniotomy

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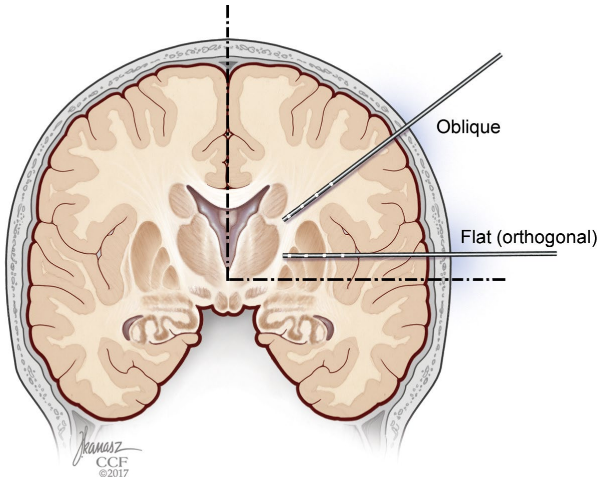

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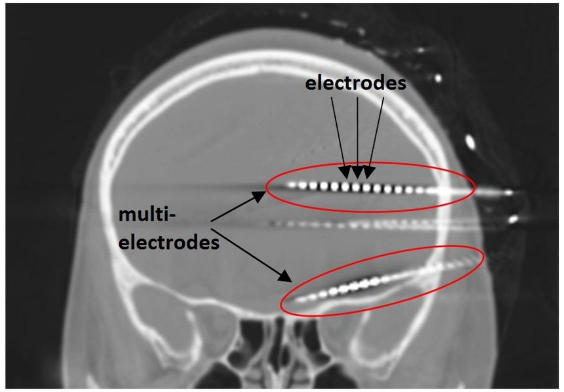


CT of SEEG Depth Electrodes [6]

Lots of referencing options:

- *Monopolar: all channels versus average of 2 white-matter contacts*
- Common-Avg (CAR): all versus avg. of all
- Gray-White Avg (GWR): all versus avg of gray/white (GWR)
- Electrode Shaft (ESR): channel versus avg of all on same shaft
- Bipolar (BR): each channel vs single adjacent neighbor
- Laplacian: each channel vs avg of two adjacent neighbors

Use-Cases: Epilepsy Monitoring

Environment: Epilepsy Monitoring Unit (EMU)

Purpose:

- Seizure classification and localization of difficult-to-capture seizures
- Medication management and assessment
- Pre-surgical evaluation for epilepsy surgery

Data rates:

- Often >500Hz in academic research institutions for >70hrs, up to a week
- Minimum of 19 channels, beyond 128 in research environments

Use-Cases: ICU/Emergency Monitoring

Environment: ICU/NICU

Purpose:

- Detecting subclinical seizures or prolonged seizures in critically ill patients
- Guiding use of powerful antiepileptic medications
- Assessing impact of head injuries on cerebral function
- Monitoring anoxia, encephalitis, neurotoxicity, post-stroke function
- Monitoring during sedation
- Evaluating encephalopathies
- Others…

Data rates:

- Often <512Hz data for <24hrs
- As low as 8 channels being used in some systems

Use-Cases: Intraoperative Monitoring

Environment: Operating Room

Purpose:

- **Real-time** monitoring of brain function
- Early detection of seizures during surgery
- Mapping functional brain areas to avoid damaging critical regions
- Localizing seizure-onset zones for resection during epilepsy surgery
- Assessing depth of anesthesia
- Detecting ischemia
- Intracranial vascular surgical procedures

Data rates:

- Wide variation, up to 16kHz
- Up to 256 channels in some cases

Use-Cases: Ambulatory EEG

Environment: Patient Home

Purpose:

- Capture infrequent events during patients’ daily routine
- Evaluating infrequent altered consciousness, confusion
- Seizure monitoring and diagnosis
- Sleep disorder assessment
- Long-term monitoring for pediatric patients with hard to capture symptoms
- Assessing medication efficacy

Data rates:

- At least 19 channels
- Typically at least 70hr studies at >200Hz

Use-Cases: Sleep Studies

Environment: Sleep Lab or Patient Home

Purpose:

- Identifying ***respiratory*** or ***sleep-related*** disorders
  - Sleep apnea, insomnia, narcolepsy, parasomnias, restless leg syndrome, others..
- Evaluating the relationship between brain abnormalities and symptom expression
  - Dysautonomia, other symptoms affecting patient quality of life

Data rates:

- Historically at least 6 EEG channels, often 16 or more
- Typically 200-500Hz for EEG data, lower for non-EEG signals (down to 1Hz)
- Duration <7hr

Use-Cases: Other

Environment: all prior environments, adding outpatient psychiatry

Purpose:

- **Routine EEG** for monitoring suspected encephalopathies, altered mental status, stroke, head injuries
- Closed-loop **stimulation devices**, mitigating seizures
- Contextual monitoring in **deep-brain stimulation** applications
- **Cognitive assessment** – a growing field with both consumer and psychiatry-driven applications
- **Neurofeedback** applications
- Other consumer-grade mindfulness, relaxation, meditation and sleep applications
- Extending beyond to motor control applications, single-neuron recordings

Data rates:

- As little as 1-10 channels in consumer systems, up to full >19 channel 10-20 systems
- Hundreds of channels in single-neuron recordings
- Duration varies widely

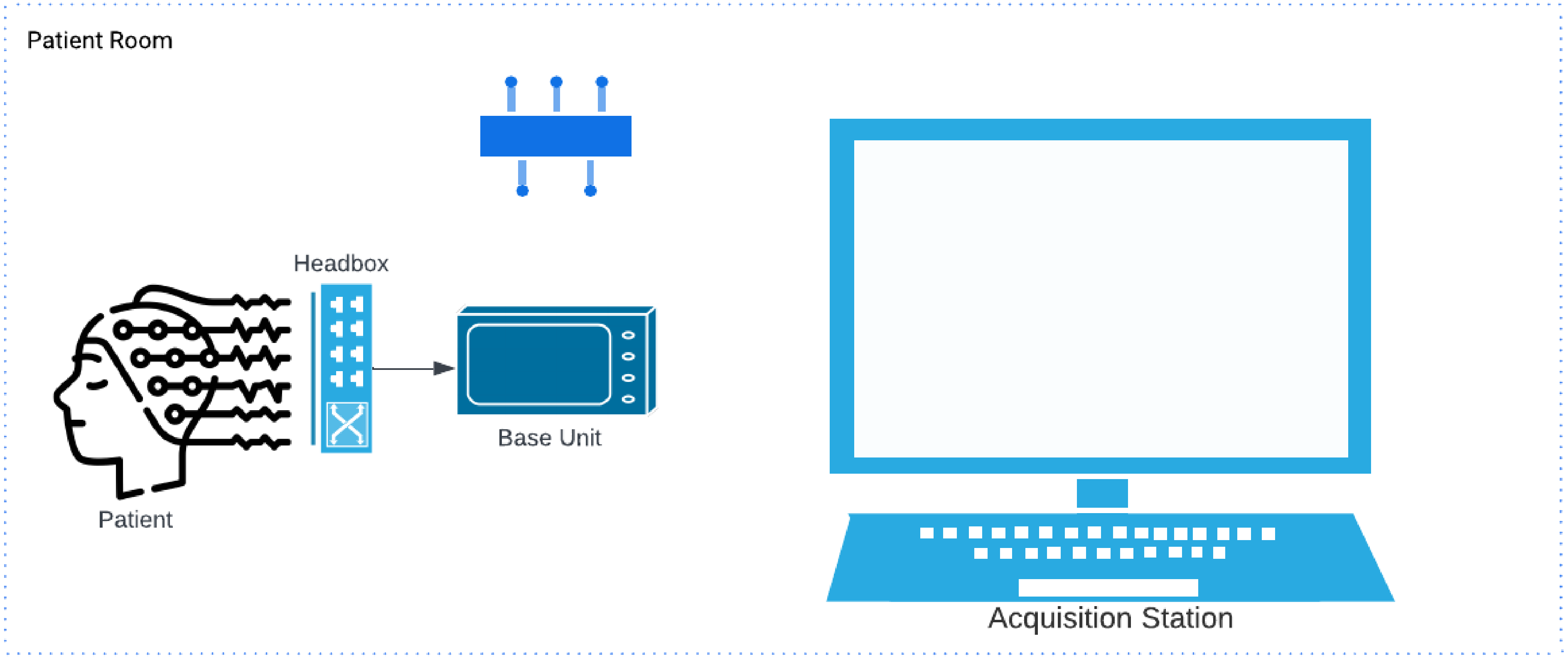
Lifecycle of EEG Data

Widely varying use-cases determine:

- *Acquisition environment and duration*
- *Resolution of sampled data points*
- *Sampling rate across channel types*
- *Number and types of channels*
- *Utility of real-time versus post-hoc review or analyses*
- *Clinical presentation*

So what about the data?

Lifecycle of EEG Data



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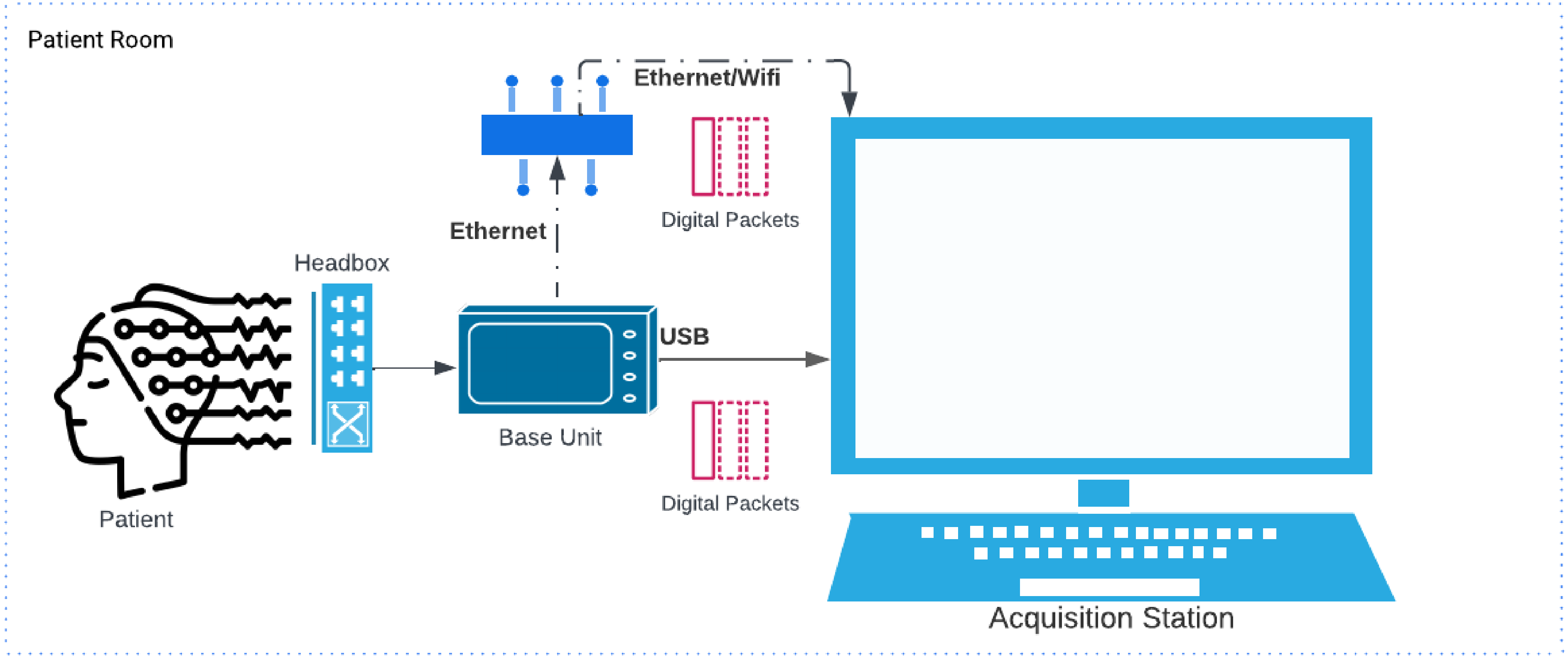

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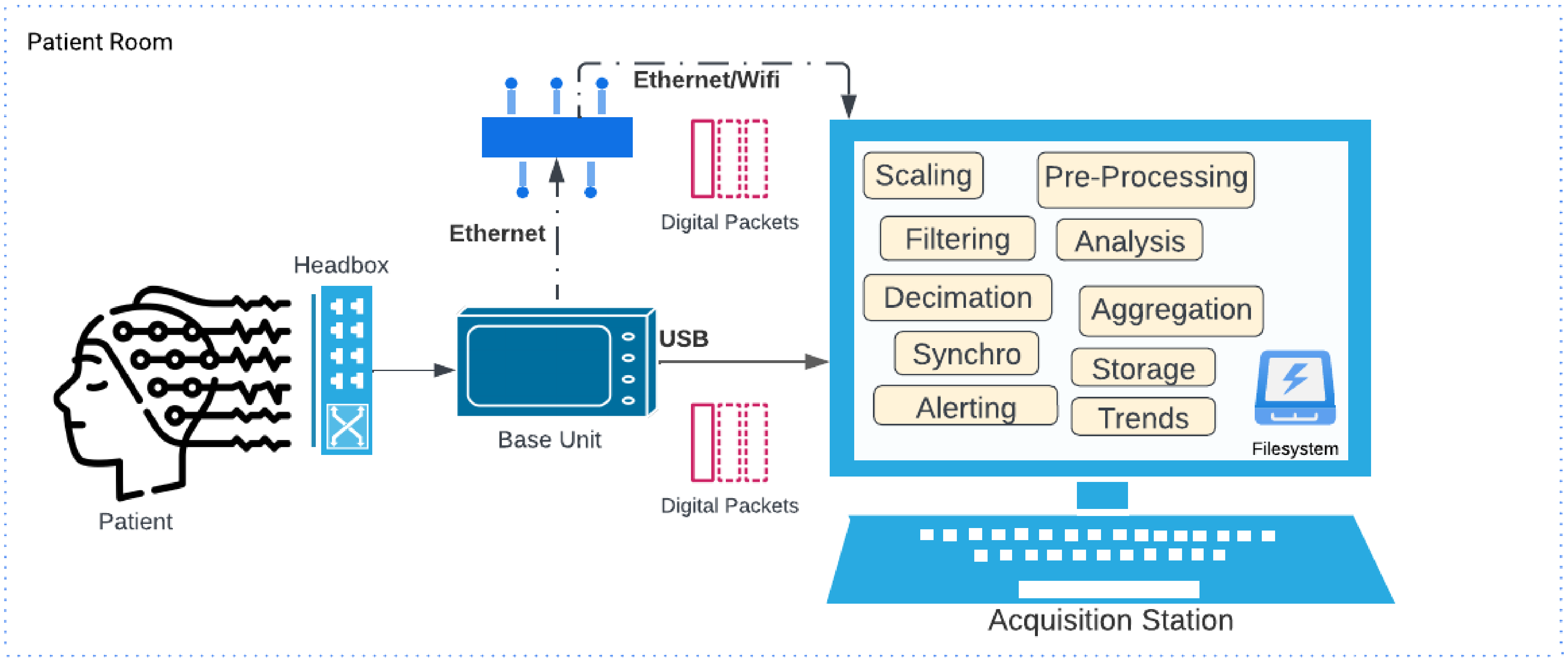

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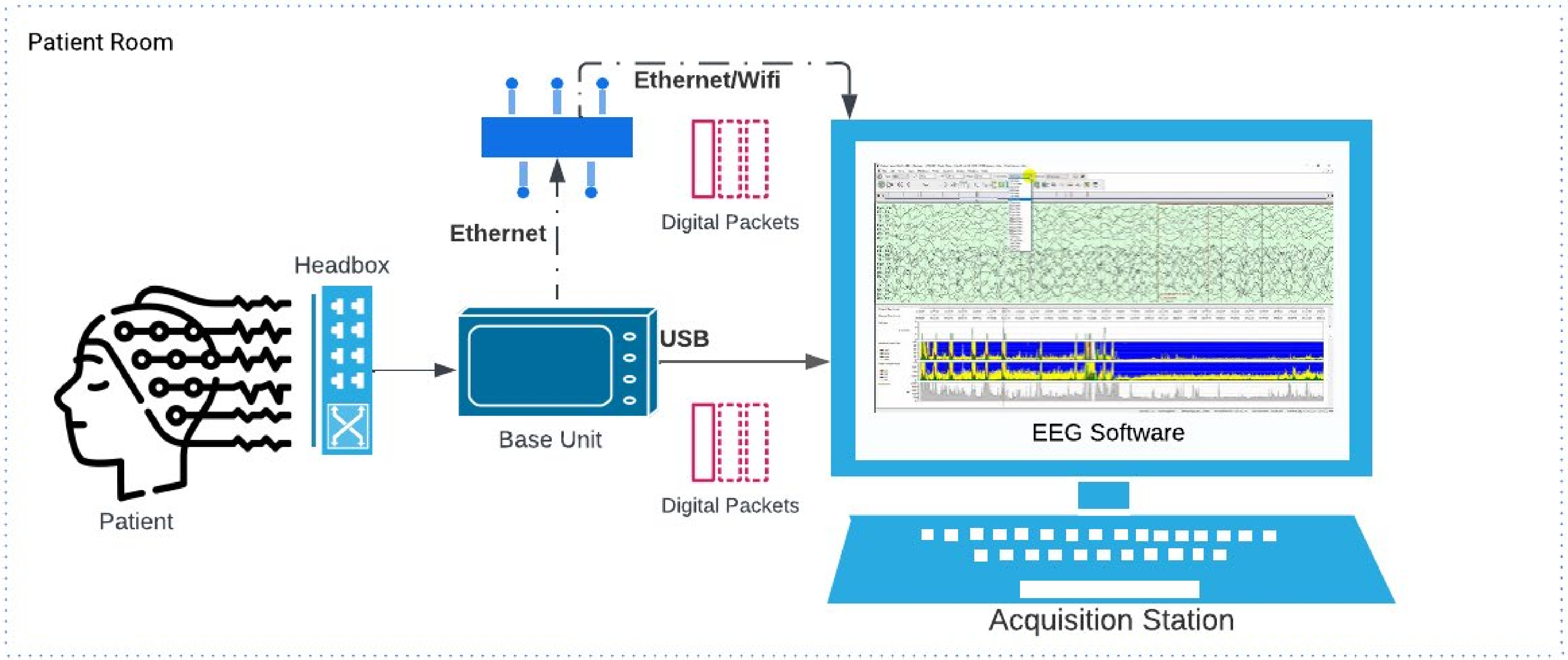

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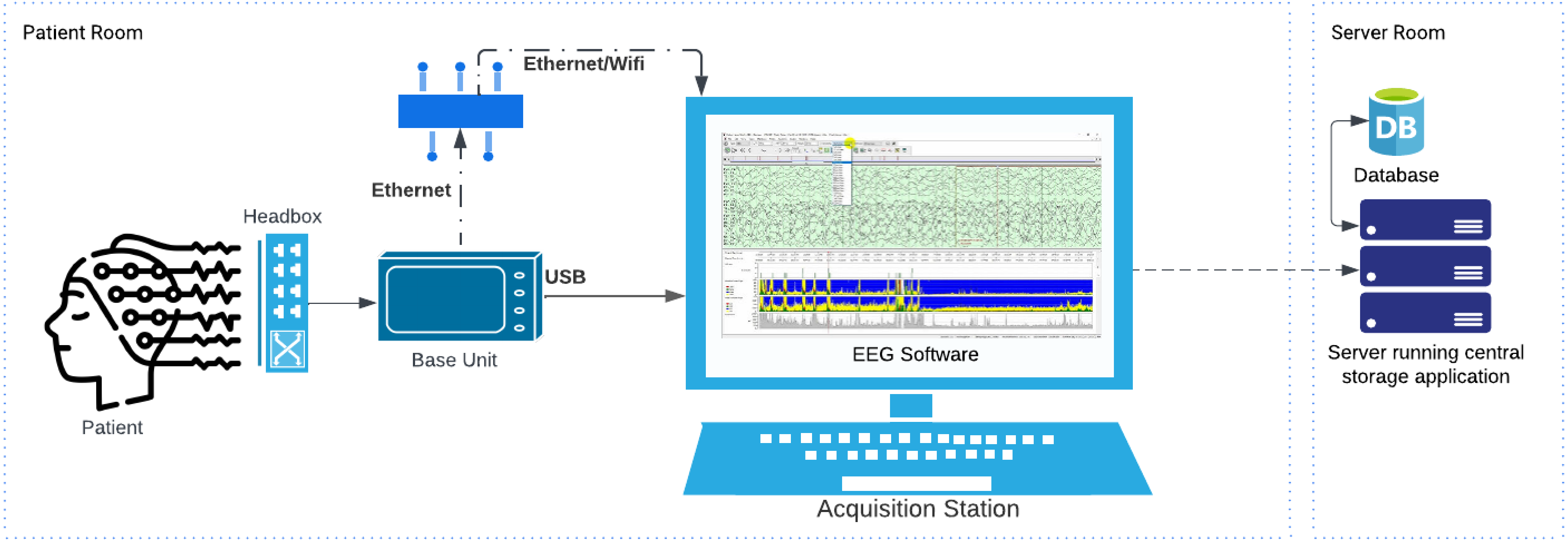

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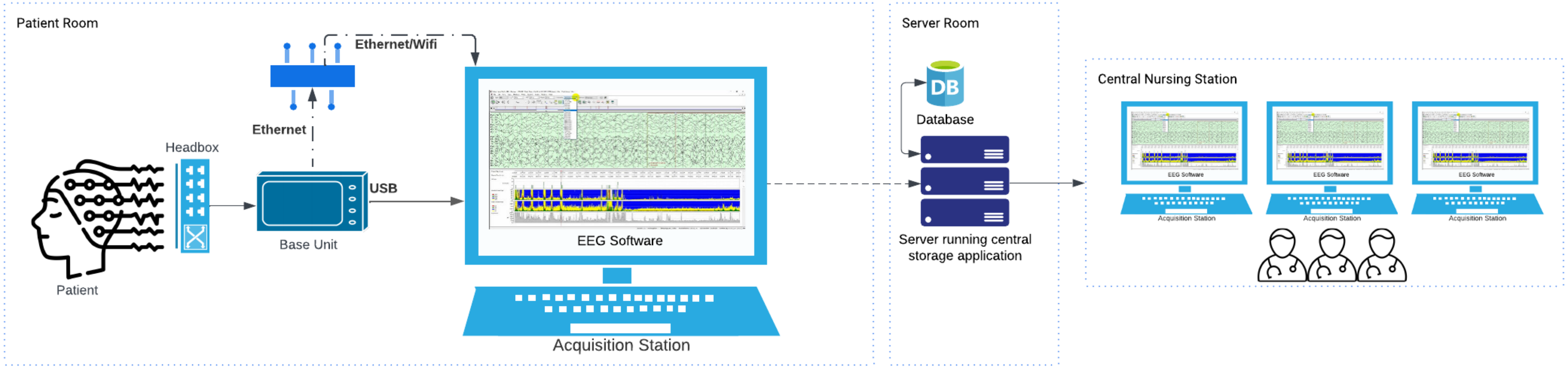

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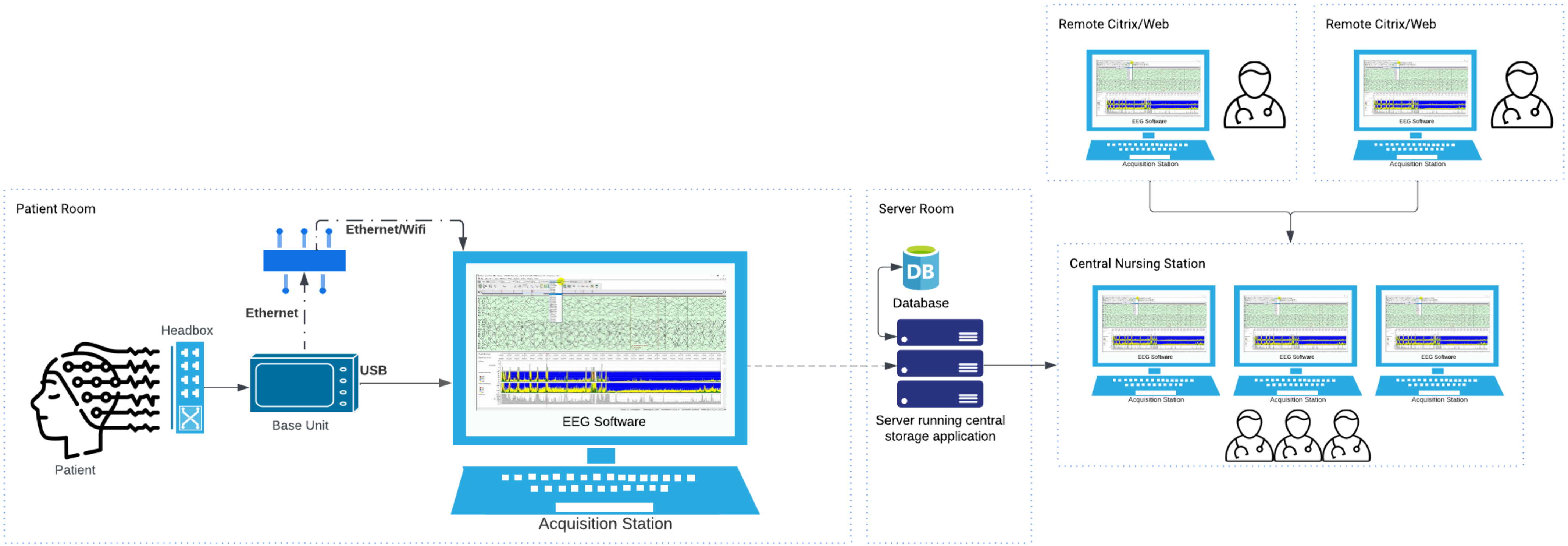

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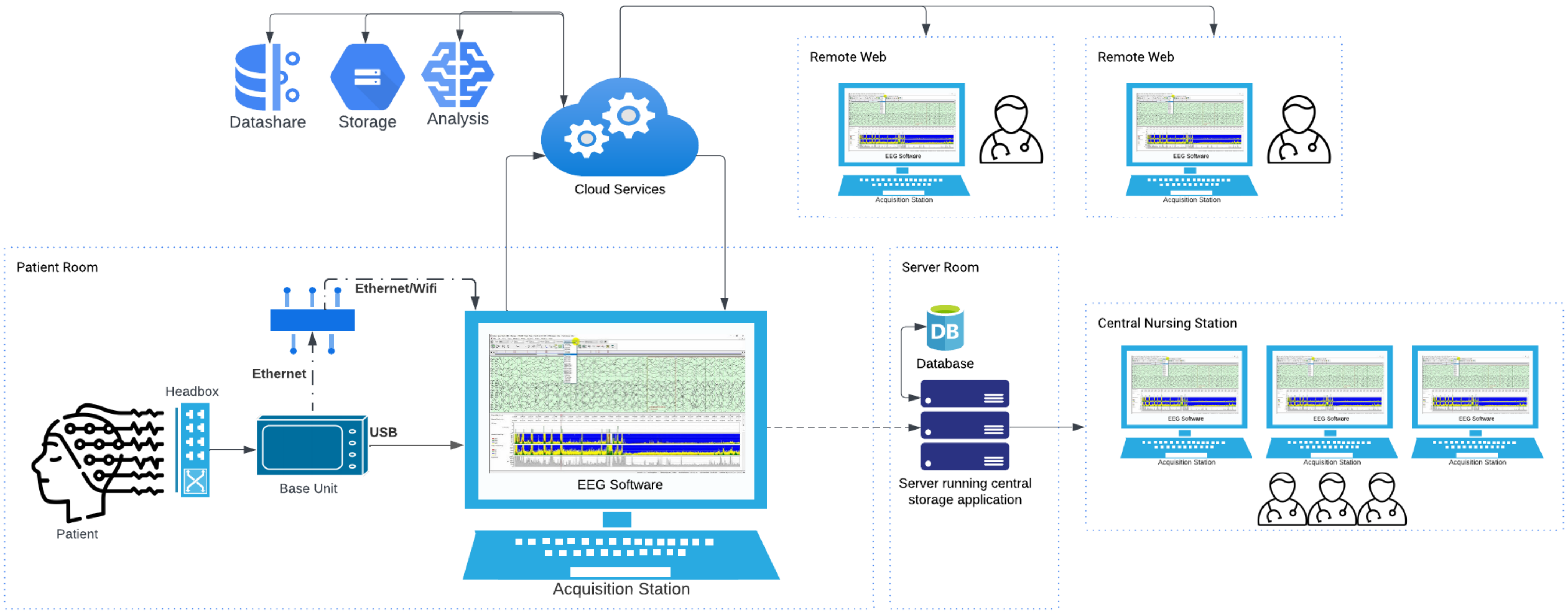


Lifecycle of EEG Data

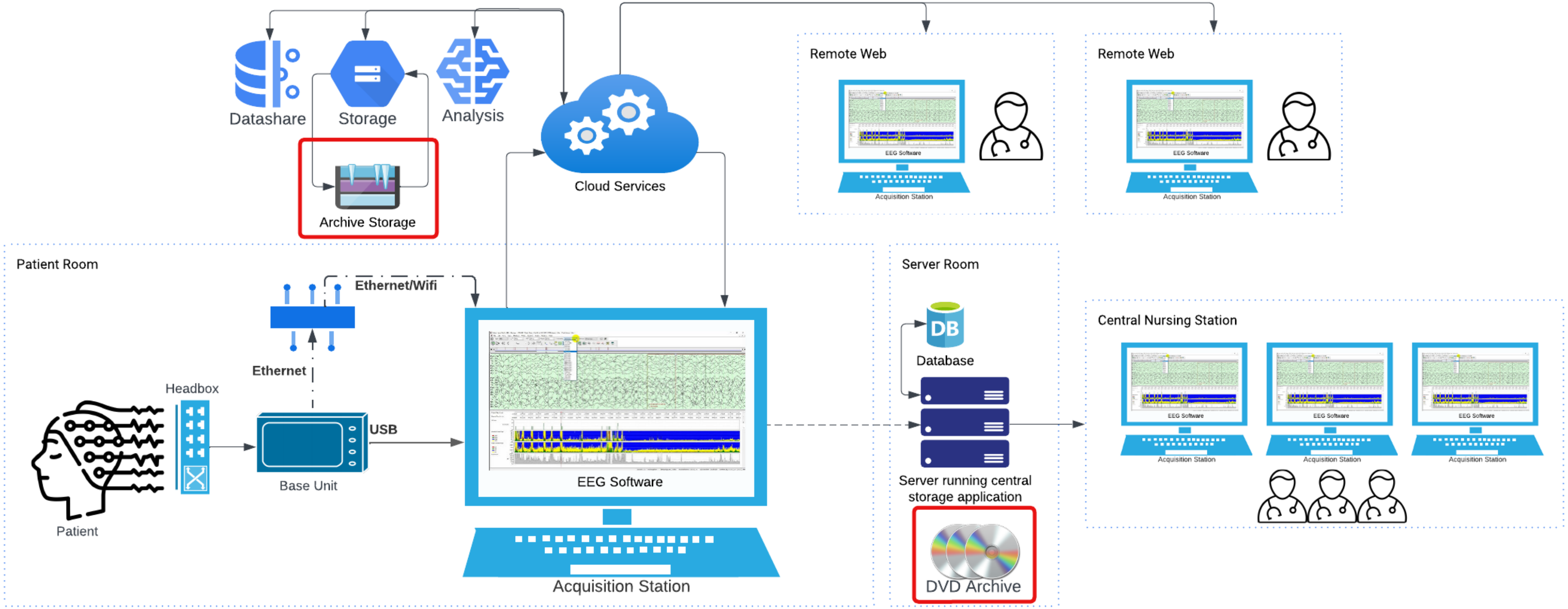
Which data do we save?

- Raw data – yes
- Decimated data – yes
- Filtered or pre-processed data – sometimes
- Clinical events and annotations – yes
- Analysis results and trends – depends
- Synchronization data for associating EEG with other signals, video – tricky
- Metadata for efficiently re-hydrating UI/UX – probably

But for how long? Where is the source of truth?

Lifecycle of EEG Data

***Archiving** data today typically means "only keep the data we thought was useful".*



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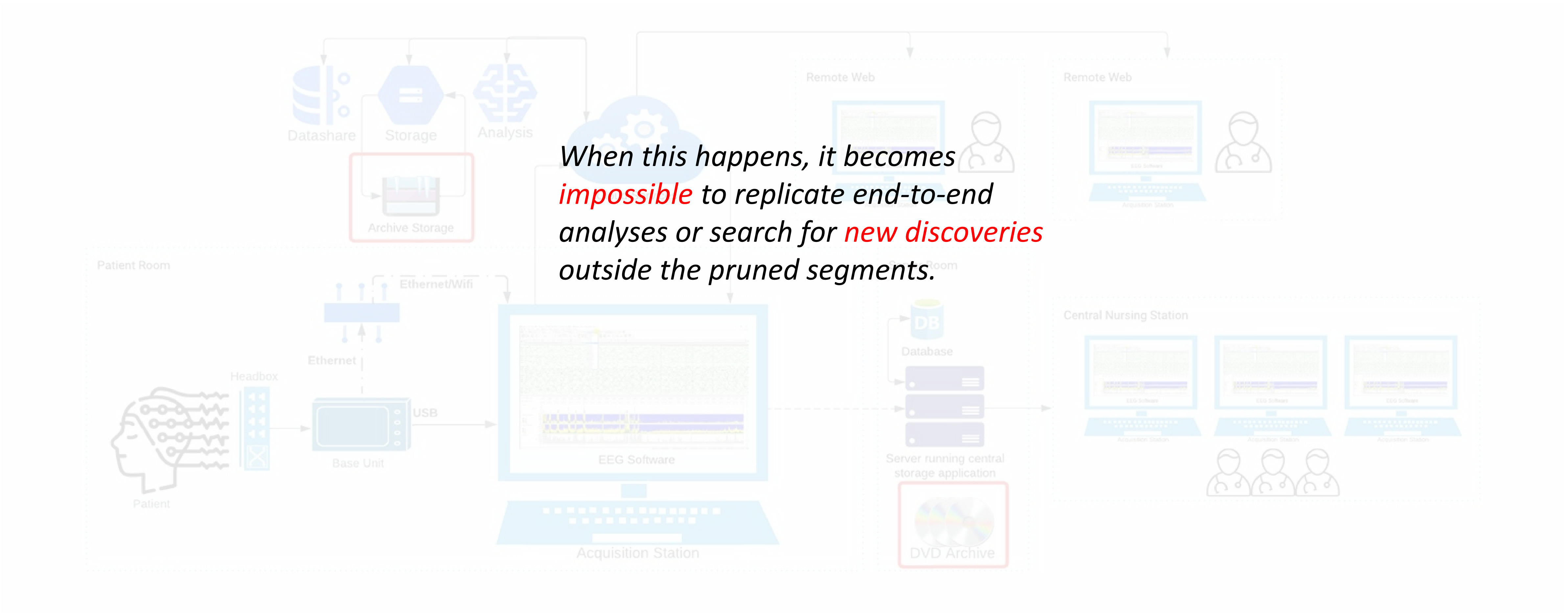
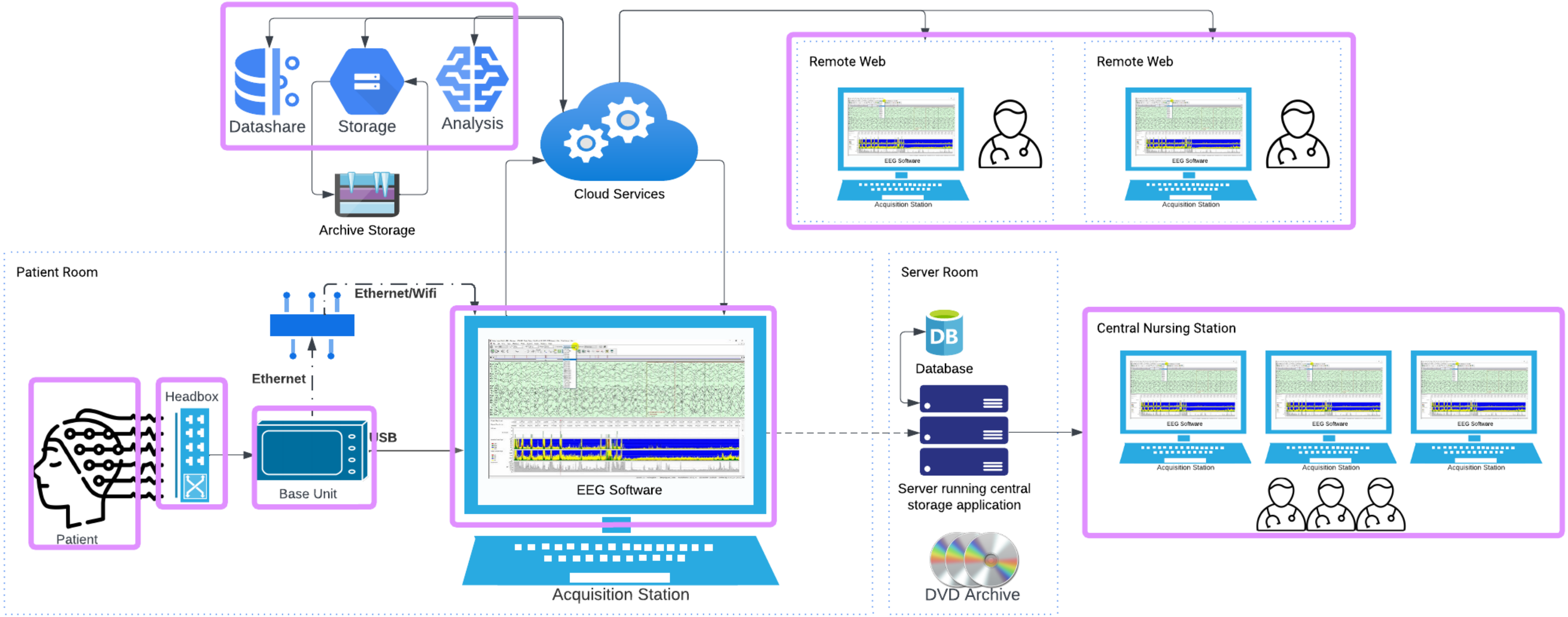


When this happens, it becomes impossible to replicate end-to-end analyses or search for new discoveries outside the pruned segments.

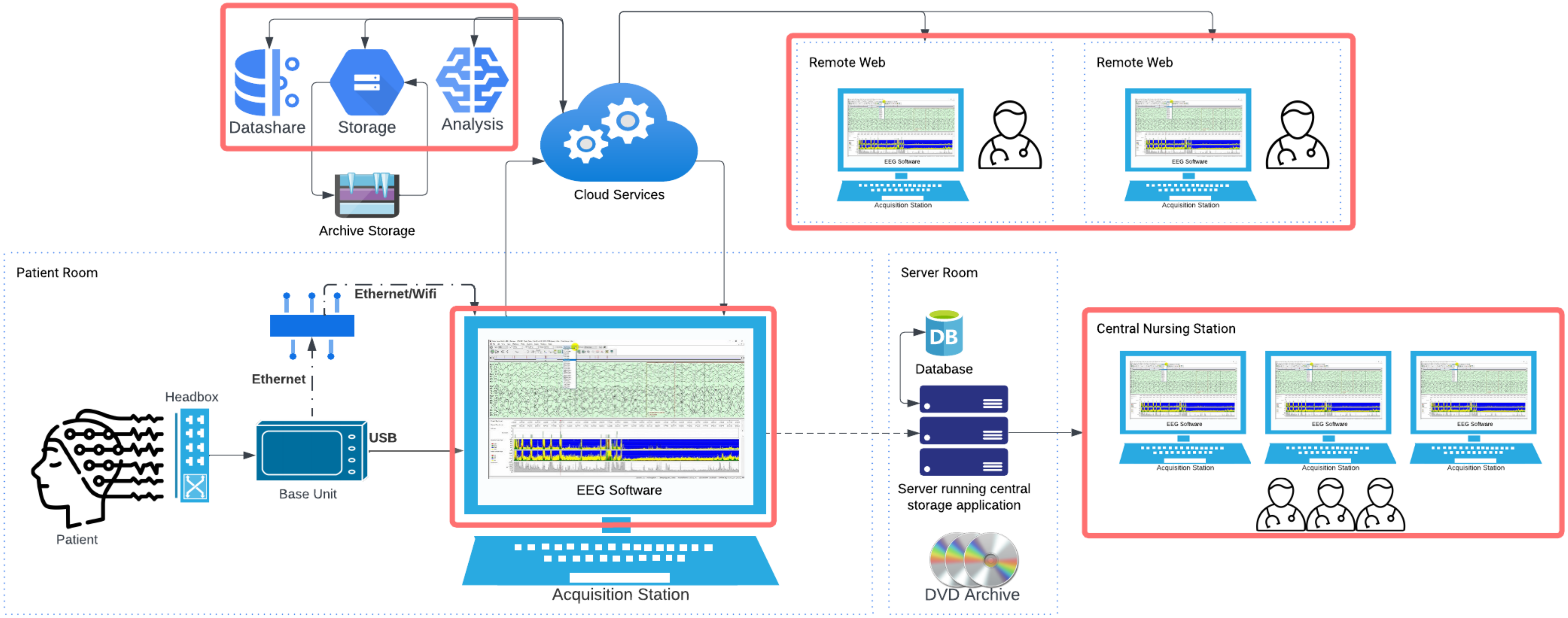
Opportunities for Clinical Presentation

Live Monitoring



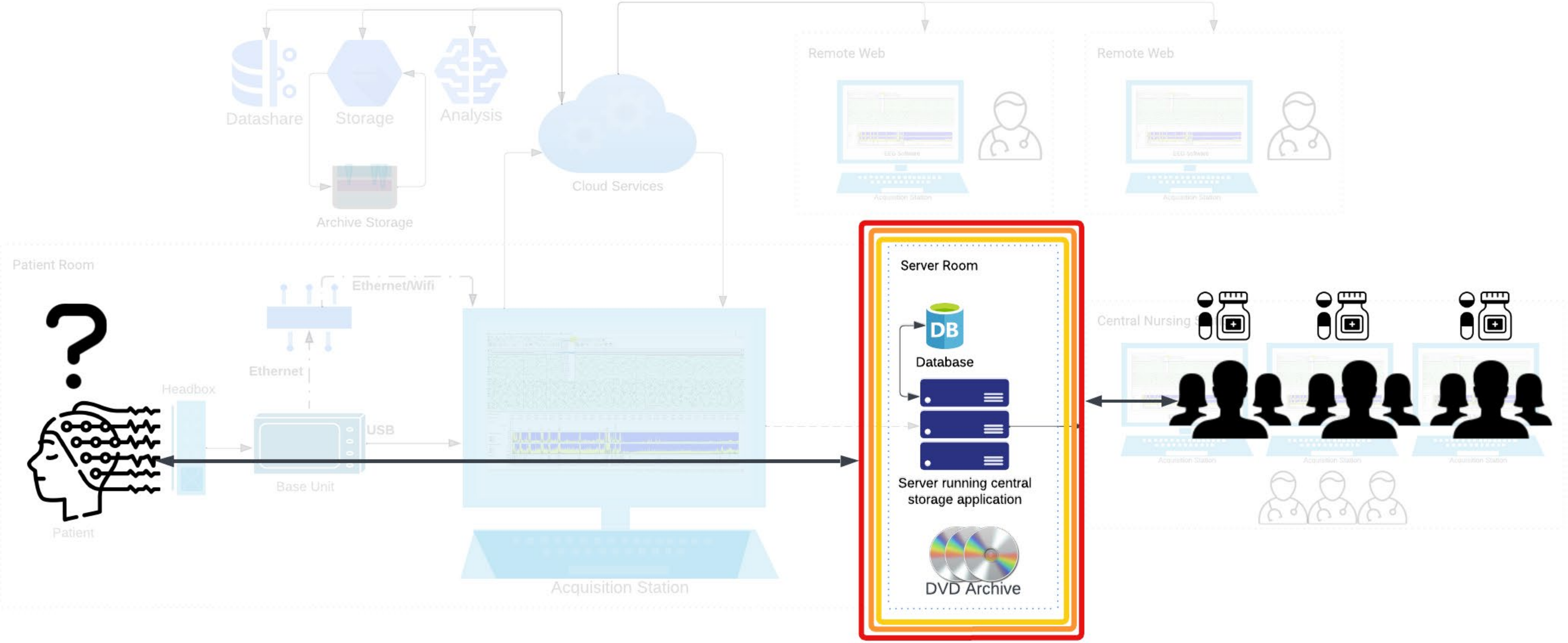
Opportunities for Clinical Presentation

Study Review



Opportunities for Clinical Presentation

But What's Missing?? *And how can we enable research?*



Enabling Clinical Research

Keep more data:

- Not just what the Dx ***thought*** was useful ***yesterday***

Aggregate more data:

- EEG + EMR/EHR + At-home/Wearables + …

Associate treatment:

- Improve characterization of seizures/events/EEG
- Draw associations with successful treatments
- Sure, go ahead and make another great seizure detector – but figure out what the properties of the detected seizures mean w.r.t. treatment.

Enabling Clinical Research

Working with Clinical EEG and multi-modal data **has been hard**:

- Accessing proprietary file formats
- Converting data to research-friendly formats
- Tapping into real-time data streams
- Dealing with gaps/breaks/pruning and data collected at different frequencies
- Synchronizing clinical notes/annotations with the original data

Natus Real-Time Data SDK:

- Get real-time data without modifying clinical PCs
- Run your own analyses and pass annotations/events back into the clinical study
- Bring your own PC

Natus File Data SDK:

- Read raw data from existing studies
- Read annotations and study info

Enabling Clinical Research

Real-Time Example: Unmodified Clinical System

NeuroWorksDataProxy: One-Time Setup

(1) *Acquire the local IP address of the target acquisition station running NeuroWorks. Run* **ipconfig** *at a command prompt if needed.*

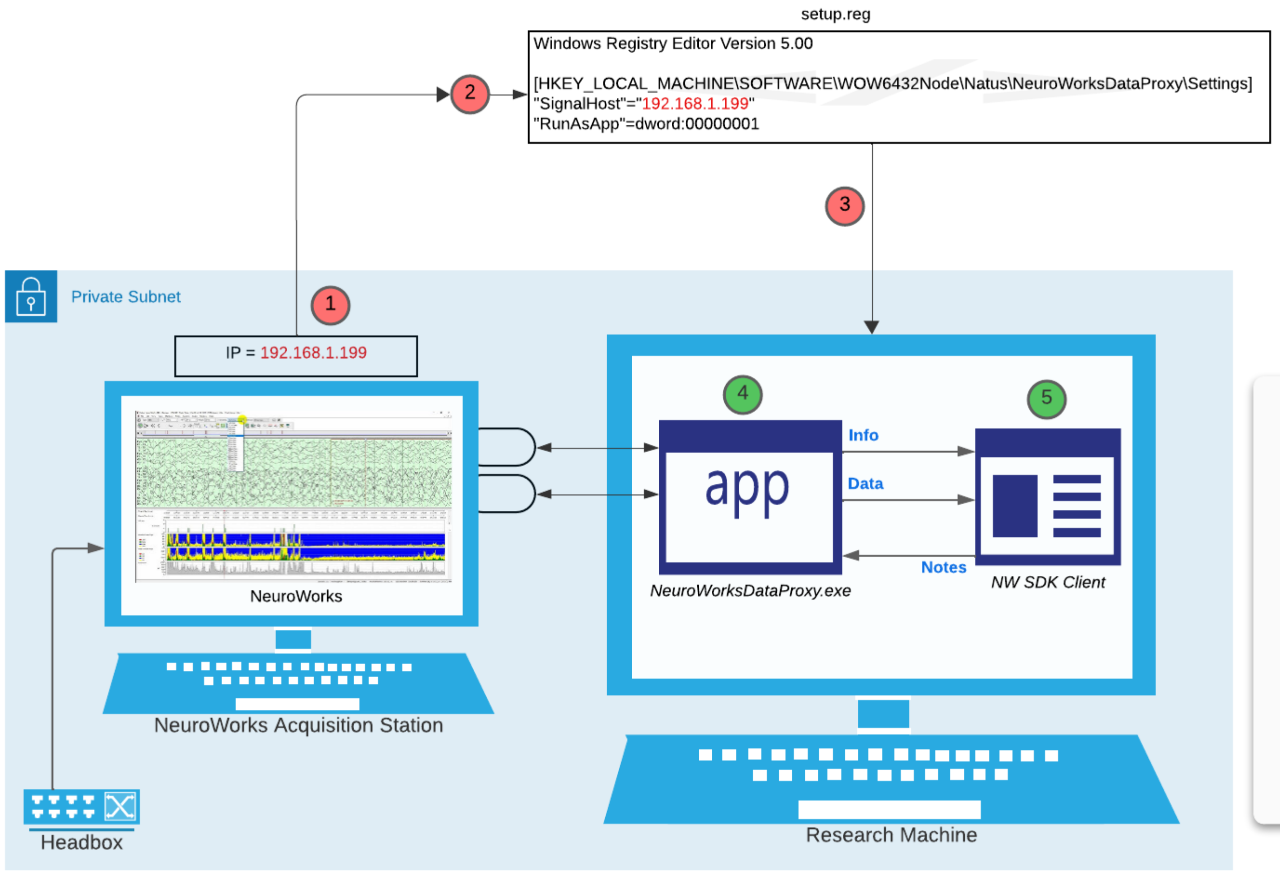
(2) *Use a text editor to modify* ***setup.reg,*** *assigning this IP address to the "SignalHost" key, in quotes.*

(3) *Execute the modified registry file by double clicking it on the Research Machine.*

Administrative permissions may be necessary on the Research Machine.

A registry key should now exist at the following location (on the Research Machine):

→HKEY_LOCAL_MACHINE
→SOFTWARE / WOW6432Node
→Natus / NeuroWorksDataProxy
→Settings



NeuroWorksDataProxy: SDK Clients

(4) *Run* ***NeuroWorksDataProxy.exe*** *by right-clicking and choosing* ***Run as administrator****.*

(5) Implement an SDK client using ZeroMQ in any supported programming language, including Python, Matlab, C++, C# and many others.

Clients of the SDK have the following capabilities:

- ***Info***: request patient/study info at any time during the life-cycle of *NeuroWorksDataProxy*
- ***Data***: receive streaming sample data in batches or one sample at a time.
- ***Notes***: place notes into the NeuroWorks study at a given sample stamp/offset.

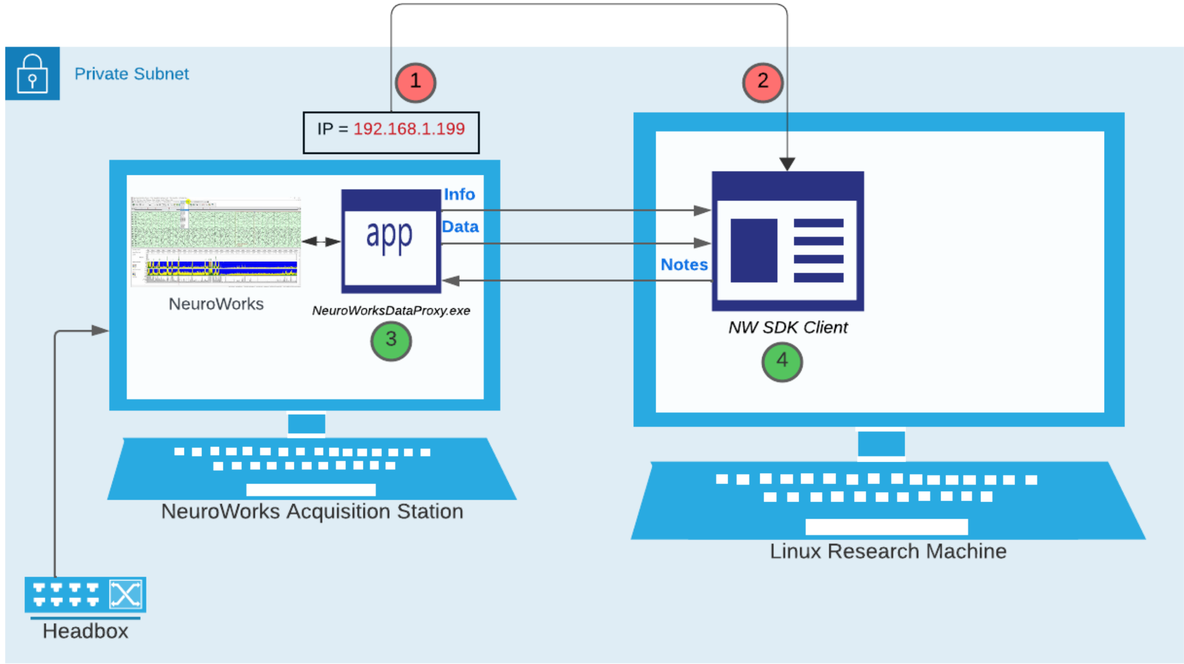
Enabling Clinical Research

Real-Time Example: Modified Clinical System to Linux

NeuroWorksDataProxy: One-Time Setup

(1) *Acquire the local IP address of the target acquisition station running NeuroWorks. Run* **ipconfig** *at a command prompt if needed.*

(2) *Use this IP address in the connection string of all ZeroMQ socket connections when implementing the SDK Client.*



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Enabling Clinical Research

Requesting SDK Access:

- Submit an NDA request ticket
- Reach out to SDK@natus.com
- Provide a GitHub account/handle for preferred SDK access

Thank You

Acknowledgements

1. Mayo Clinic. "Electroencephalography (EEG)." Mayo Clinic, https://www.mayoclinic.org/tests-procedures/eeg/about/pac-20393875.
2. Brienza, M., Mecarelli, O. (2019). Neurophysiological Basis of EEG. In: Mecarelli, O. (eds) Clinical Electroencephalography. Springer, Cham. https://doi.org/10.1007/978-3-030-04573-9_2
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