vision

sUbtiTlE hErE (suGgeStiOnS?)

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## Introduction

Utilization of simulation-based training for healthcare providers has expanded rapidly since the early 2000’s, when the first “high fidelity” patient simulator mannequins were made available by manufacturers at price points accessible to smaller programs. Over that time, simulation technology has diviersified considerably, lowering per-item cost while deepening the “stack” required for an appropriately-equipped laboratory.[[1]](#footnote-23) Though buy-in costs have remained high, the health education sector views simulation technology as valuable,[[2]](#footnote-24) and there is accumulating evidence of improved education outcomes from simulation training across an increasing spectrum of psychomotor skills.[[3]](#footnote-25)[[4]](#footnote-26)[[5]](#footnote-27)

Data capture systems are an essential part of the technology stack for modern simulation laboratories; they are complex, expensive, specialized services which are difficult to maintain without access to a specialist. In addition to engineering challenges, the decoding, encoding, and transmission of AV data is deeply mired in a crytpic network of patent protections and proprietary technologies.[[6]](#footnote-28) Simulation laboratories in need of AV services have few options: select one of several commercially available products, contract for a customized system, or develop their own. Each option introduces significant up-front and downstream costs, and the latter two are not realistic for a majority of simulation centers.

These items encourage vendor dependence, especially in resource limited laboratories, and increase the dfficulty of accurate decision-making by consumers. Vendors are not forthcoming on details related to the architecture, implementation, or performance of their service, and, if it is made available, the information is written in a marketing language that conflates and obfuscates important technical details.[[7]](#footnote-30) Given that AV systems are an essential debriefing tool, and that debriefing is the most important part of simulation,[[8]](#footnote-31)[[9]](#footnote-32) difficulty matching tool to task degrades Return on Investment (ROI) for simulation laboratories and their constituents.

*vision* is an asynchronous, distributed, open-source data system for medical simulation built with reactive microservices. It offers a service-equivalent model for the capture and utilization of AV data in medical simulation laboratories, then expands this model to accomodate modern data technologies. It is based on patent- and royalty-free technologies, implemented with state-of-the-art architecture patterns, and targeted at commodity hardware. In all, *vision*

1. Lowers the cost-of-entry for simulation laboratories seeking a data and AV service.
2. Provides a needed focal point for the medical simulation community to examine critical issues related to these services.
3. Allows simiulation laborities to meet *their own* needs by providing robust, flexible, and extensible interfaces for emerging technologies.

Moving forward, some nomenclature will be helpful.

* *Distributed Systems* are a collections of indepdent computers that appear to their users as a single system.
* *Reactive Microservices* are autonomous, self-contained programs that interact asychronously at the request of another service. They communicate via protocols, and may be many miles apart.
* *Formats* are containers for data. Audiovisual formats contain data such as audio tracks, subtitles, and image streams.
* *Codecs* are used to compress (encode) and decompress (decode) formats, reducing file size and improving the efficiency of transmitting data. They are highly specific algorithms and must be carefully paired with a use case.
  + *Encoders* compress data for storage or transmission.
  + *Decoders* decompress data for viewing.

## Engineering Challenges

Capture and delivery of distrubted data is *not* an encapsulated service, despite vendors’ attempts to present their services otherwise. It relies on an extensive technology stack crossing many domains that evolve independently and according to their own needs. Thus these vendors are consumers and users of a wide range of technology products used to deliver a service to *their* customers, who implicitly “buy in” to these decisions when they deploy a given service. Though there is nothing inherently wrong with this practice, it is heavily obfuscated in marketing and sales materials, which focus on per-device specification and leave the buyer to discern whether their deployment environment can acheive advertised performance. Given the cost and specificity of deploying a distributed data service within a medical simulation laboratory, consumers deserve a chance to review and question decisions ostensibly made on their behalf.

### User Experience (UX)

Humans have low tolerance for latency when interacting with a computer.[[10]](#footnote-35) Engineering a consistent experience across a distributed, high-bandwidth service is extremely difficult. This is due to the increased complexity of distributed systems and their depedence on networks for data transmission: if the network is underperfomant, the system has limited ways to adjust, with each adjustment adding complexity and consuming system resources.

Near real-time is a typical use case for a medical simulation data system. Captured data are expected to be available immediately following the conclusion of a simulation exercise and delivered smoothly enough to not interrupt the educational process. Distributed systems also distribute their errors, so when a system underperforms–as it is occassionaly guaranteed to do–it can be difficult to discern the source *even for those with great familiarity*.[[11]](#footnote-37)

Vendors sell closed technology, and spend precious little time at client sites. They cannot be expected to have robust knowledge of a client’s network characteristics, nor can they be expected to change their product if it is a bad fit; which will be discovered *after* the client has made a capital investment. This lack of transparency makes performance guarantees tenuous, gives vendors a side-out for issues (blame the network), and strongly limits the ability of a simulation laboratory to get the most out of their service. In general,

lack of transparency => hindered diagnoses => difficult to address local problems [graphic]

While *vision* is certainly a complex distributed system prone to the same set of issues, it is **reviewable, modifiable, and provides information-rich logs** which empower simulation laboratories to adapt *vision* and/or their network to better meet the needs of their users.

### Limited Ecosystem of Essential Technologies

What a simulation data service can offer is limited by what its clients can consume. Codec support on end-user devices cannot be taken for granted, nor can it be assumed client devices are properly equipped to deliver a reasonable experience. Considering the essential “base” technologies, there are

* Two (2) widely-supported AV formats: H.26\* and VP9.
* Four (4) common browsers: Chrome, Edge, Firefox, and Safari.[[12]](#footnote-39)
* Five (5) common operating systems: Andriod, iOS, Linux, MacOS, and Windows.
* One (1) appropriate streaming method with one (1) standard impelemtation: Adaptive Bitrate (ABR) Streaming via MPEG-DASH.[^abr-implementations]

That’s 2\*4\*5\*1, or 40, possible combinations, and, looking from the client’s side, we can safely exclude Linux and scale back to 2\*3\*4\*1, or 24, *likely* combinations. Vendors may also choose to develop a native client, sidestepping the browser and reducing the total number of combinations to 2\*4\*1 (8), but more likely to 2\*3\*1 (6) because tablets predominatly run Andriod or iOS, and occasionally Windows.

Considered from the service side, there are

* Two (2) likely operating system choices: Linux and Windows.
* One (1) standard utility for maniuplating AV data: FFmpeg.[[13]](#footnote-40)

That’s 2\*1 (2) combinations. The operating system does little more than host a simulation data service and its associated processes. This job is certainly important, but modern operating systems are reliable enough for engineers to put a majority of their focus elsewhere and assume the operating system is able to support their service.

Programming languages are discounted because even bad code runs fast on modern systems. Despite probable claims from vendors that their service is faster because it is written in a given language, an overwhelming majority of computationally-intensive tasks are handled by third-party services. Simulation data services are, a priori, distributed systems, so engineers are obligated to follow a single design pattern regardless of their choice of language. Architecture–which determines how a service distributes computational load–is a far better predictor of performance.

Thus simulation data services fail to meaningfully differentiate, contrary to vendor claims, and their closed-source nature makes it impossible for consumers to evaluate which implementation they desire. *vision* is robustly open-source, and based entirely on open-source technologies, allowing anyone to deeply review the service and its design.

### Security

Security is a central problem of information storage, transfer, and retrieval.

### Globally Escalating Computational Overhead

## Barriers to Competition

Research and development of AV technology occurs in a niche market protective of Intellectual Property (IP) where there is no clear incentive for collaboration. Large companies, who own the platforms on which codecs execute, have considerable influence over standard adoption. Reporting in October 2017 for August 2016 data, smartphone market shares for Apple and Samsung were 35.0% and 35.2% respectively,[[14]](#footnote-44) who collectively occupy 70.2% of the smartphone hardware market. In addition, as of the third quarter of 2016 Google’s Andriod operating system is estimated to occupy 88% of global smartphone shipments,[[15]](#footnote-46) leaving 12% for the *remaining* group of smartphone operating systems.

### Minority Control of Market

The AV marketplace is largely composed of small, specialized companies investigating problems of well-defined scope. By-and-large, however, market activity is directed by the small number of large companies with deep interests in AV transmission. This state likely owes to the blurry line between *technology which processes signals* and ownership of the *content encoded in those signals*. In brief, technology is used to sell content: the market for consumers of content exponentially larger than the market for specialized hardware and software, thus the bulk of revenue is available to the advertisers who use AV processing technology as an encapsulated service.

H.26\* formats are based heavily on patetented technology.[[16]](#footnote-49) And while a reasonable number of other formats are available, many require some type of licensing or implement part(s) of an H.26\* format. A majority of these agreements separate encoding, streaming, and decoding; which allows the introduction of fees at each step in the delivery chain.

AV transmission standards largely concern the owners of content delivery services, who charge for the privilege of access to users of their networks. From 2006 to 2016, internet advertising revenues in *the United States alone* grew approximately 429.0% from $16.9 billion to $72.5 billion,[[17]](#footnote-52) with the “top ten” (10) companies commanding 69-75% of revenue over the same period.[[18]](#footnote-54) In this case standardization is a revenue optimization strategy: the more devices end users own which support the standard, the larger the potential customer pool for advertisers.

Though VP9 is widespread, and the standard format for YouTube, Apple has repeatedly passed on implementing it in Safari for iOS or macOS.[[19]](#footnote-55) Thus Safari users cannot access VP9-encoded content and must change browsers or rely on vendors to support multiple formats, which introduces additional frustrations for users.

4K -[[20]](#footnote-56)

### Patents and Ownership

The first digital AV format, H.120, was published by a telecommunications industry group in 1984.[[21]](#footnote-59) It was not usable, but a revision to it, H.261, became the first production-ready standard when it was published in 1988. A number of formats were introduced as digital audio and video data proliferated throughout the 1990s but none found the traction of H.261 and its successors, which emerged as the de facto industry standard–studied, licensed, or re-implemented by a majority of avaialble AV formats.

Numerous free and/or open source options have been introduced concurrent to the rise in popularity of the H.26\* standards. Generally these can be divided into encoding **libraries**, such as *libx264*, *libx265*, and *libpvx*–for H.264, HEVC/H.265, and VP9 respectively–and **formats**, such as Matroska, Ogg, WebM, and VP9–which define data structures and are used to interpret individual AV files. Here some interesting catch-22s arise

1. While the codecs *libx264* and *libx265* are free and open sourced, the H.26\* family of formats is not. Anyone wishing to use them in production must negotiate a license agreement via
   * MPEG LA, LLC. Private, for-profit, licenses H.26\* patent pools.[[22]](#footnote-60)
   * HEVC Advance. Private, for-profit, licenses H.265/HEVC patent pools.[[23]](#footnote-61)
   * Velos Media. Private, for-profit, licenses H.265/HEVC patent pools.[[24]](#footnote-62)
   * Individual arrangements with associated patent holders.
2. H.26\* *and* VP9 include patent-protected technology.
   * In certain cases, patent pools and individual holders allow royalty-free use of H.26\* formats.[[25]](#footnote-63)
   * Google, the owner and developer of VP9, grants an “in-kind” license that terminates on patent litigation.[[26]](#footnote-64)
3. H.264 is ubiquitous and there is already widespread support for HEVC/H.265 *and* VP9. Exposure to royalty fees depends on the engineering of a particular content service.[[27]](#footnote-66)

As of this writing, there are at least three (3) patent pools for H.265/HEVC,[[28]](#footnote-68) one (1) for the H.26\* pools,[[29]](#footnote-70) and at least one significant patent holder which does not participate in any pool.[[30]](#footnote-71) Inconsistent participation by patent holders has been identifed as a barrier to adoption of the HEVC standard,[[31]](#footnote-73) and waiting in the wings is the Alliance for Open Media’s AV1–an as-of-yet untested format whose adoption is expected but by no means guaranteed.

## Addressing Challenges and Removing Barriers

* aligned with open source tools
* avoids vendor/platform (clear up) lock-in
* inclusiveness (“community aware”)
* increases visibility of difficult engineering issues
* fundamentally different motivations

## Summary

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