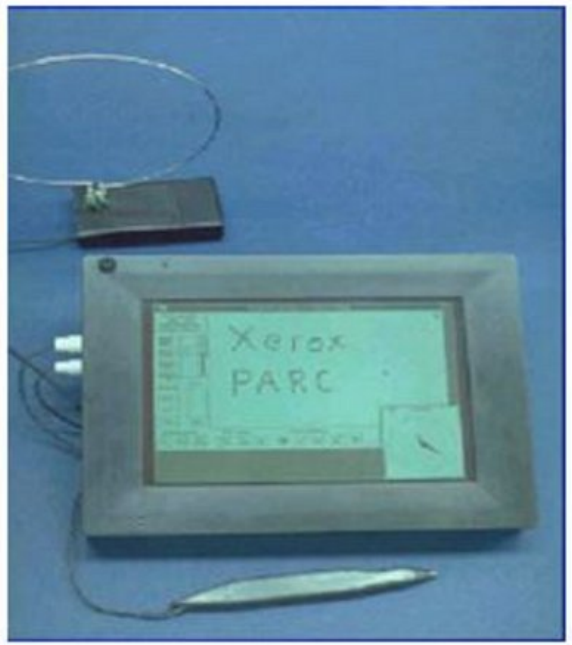
Mirror Hall

Virtual network displays to bridge mobile and desktop

Liveboard

ParcPad



ParcTab

In 1993, Xerox PARC pushed for “ubiquitous computing” [1]

Context

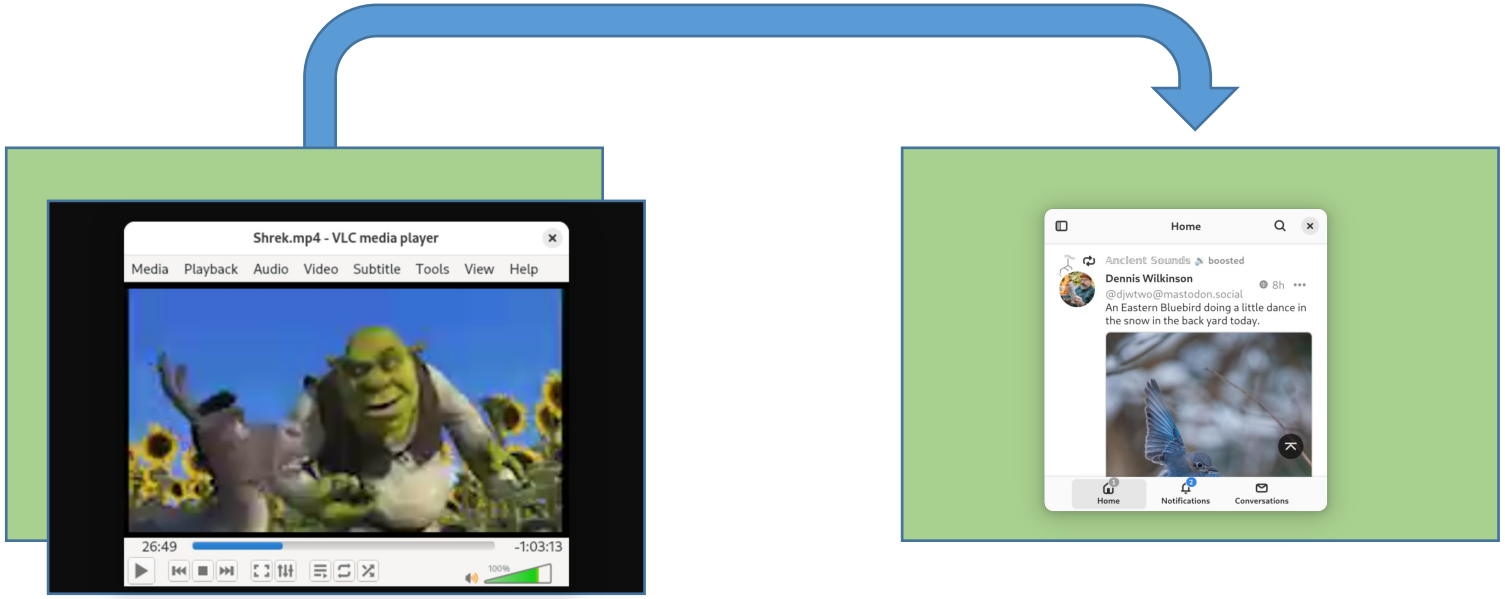
- Why are devices still so hard to interface with each other?
  - E.g., convergence, peer-to-peer file sharing, are still wonky
  - Industry favoured proprietary products over long-lasting protocols
- Some solutions for wireless desktop mirroring exist...
  - Moonlight, Sunshine -> fast and stable, mostly for games
  - GNOME Network Displays is a Chromecast/Miracast sharing tool
- We miss an open solution for *virtual* desktop mirroring
  - i.e., extending your screen on another device

Simple mirroring

Miracast chromecast ...

Records the primary screen, and **replicates** it on another.
Lots of good solutions on Linux, all using screen recording API.

What about *virtual* mirroring?



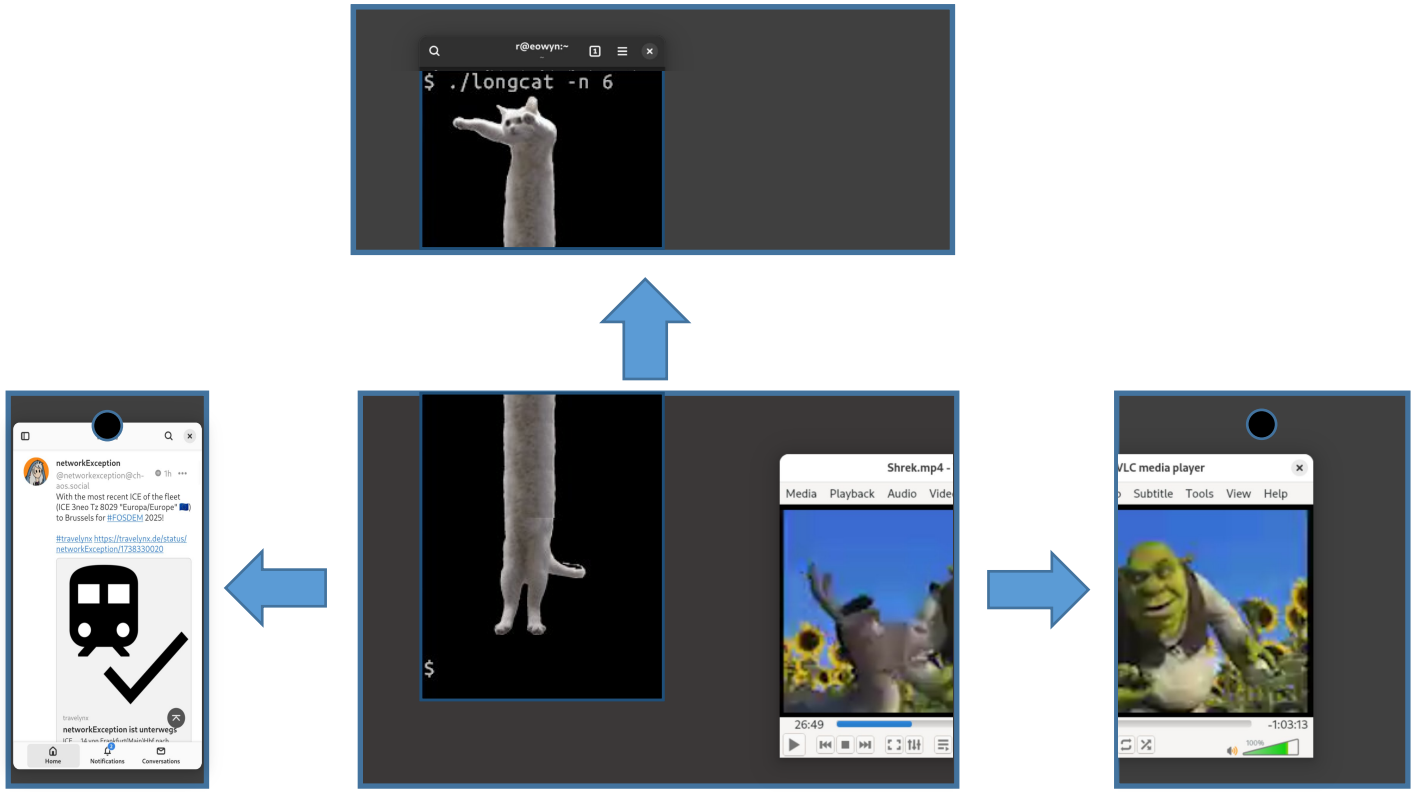
This is possible! It requires spawning a virtual (headless) display, if the WM or graphical stack cooperate.

Apple Sidecar allows to use some iPads as extended screens for macOS [2]

Existing solutions wouldn’t work

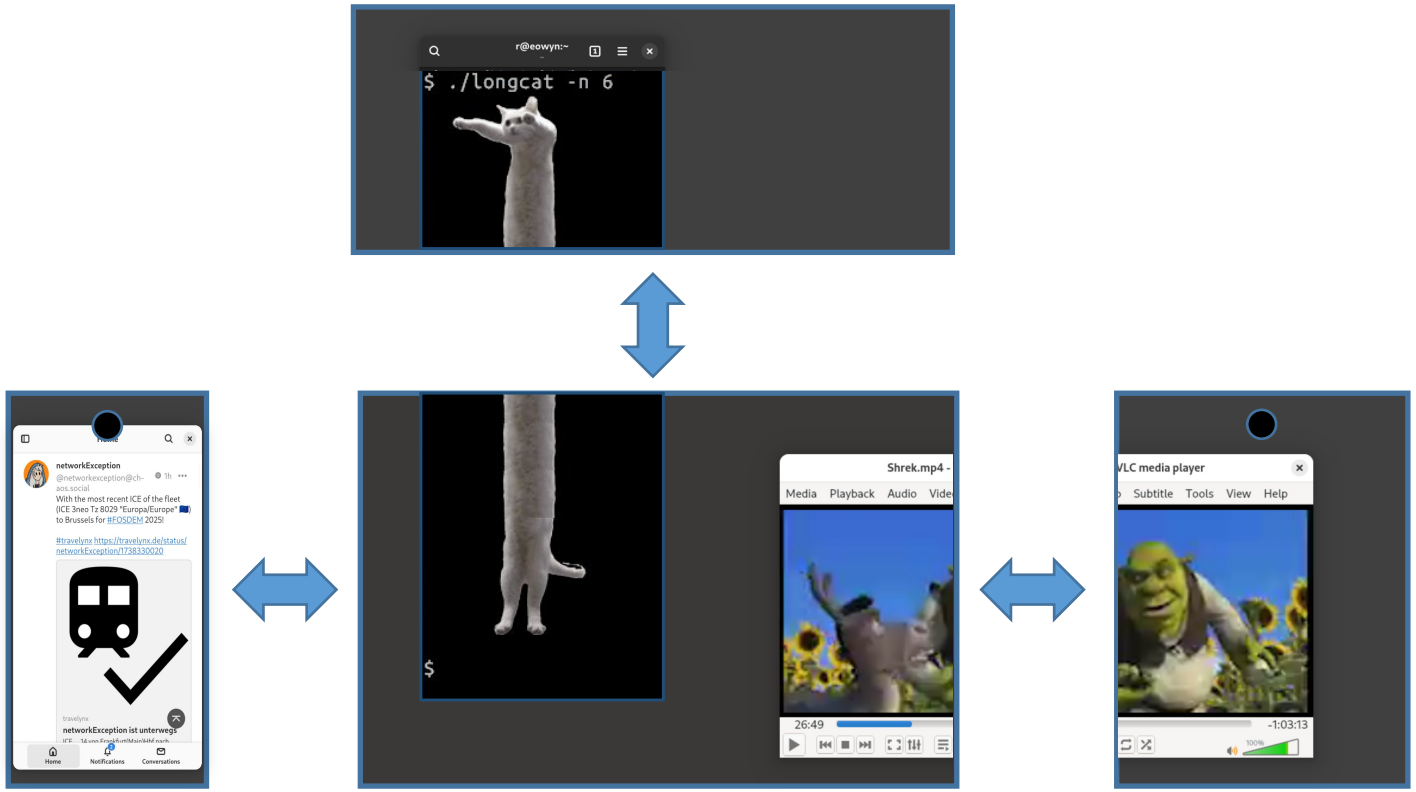
- It’s a maze of proprietary protocols :(
  - Miracast, Chromecast, AirPlay, Sidecar, DisplayLink, … —> similar core idea
- Existing wireless display standards have high latency – usually ~1s!
  - Mostly TCP-based -> optimized for stability over speed (e.g. for video playback)
  - Implementations are often software-encoded
- All solutions are “unidirectional”: streamers only
  - Turning a Linux device into a Miracast/Chromecast sink is hell
  - Requires e.g. firmware or NetworkManager patches for ad-hoc (Wi-Fi direct)
- Usually meant for one stream at a time

Virtual mirroring, but *multiplied*?



Still possible, but some **conditions apply**: availability of video buffers, hardware encoding buffers, etc.

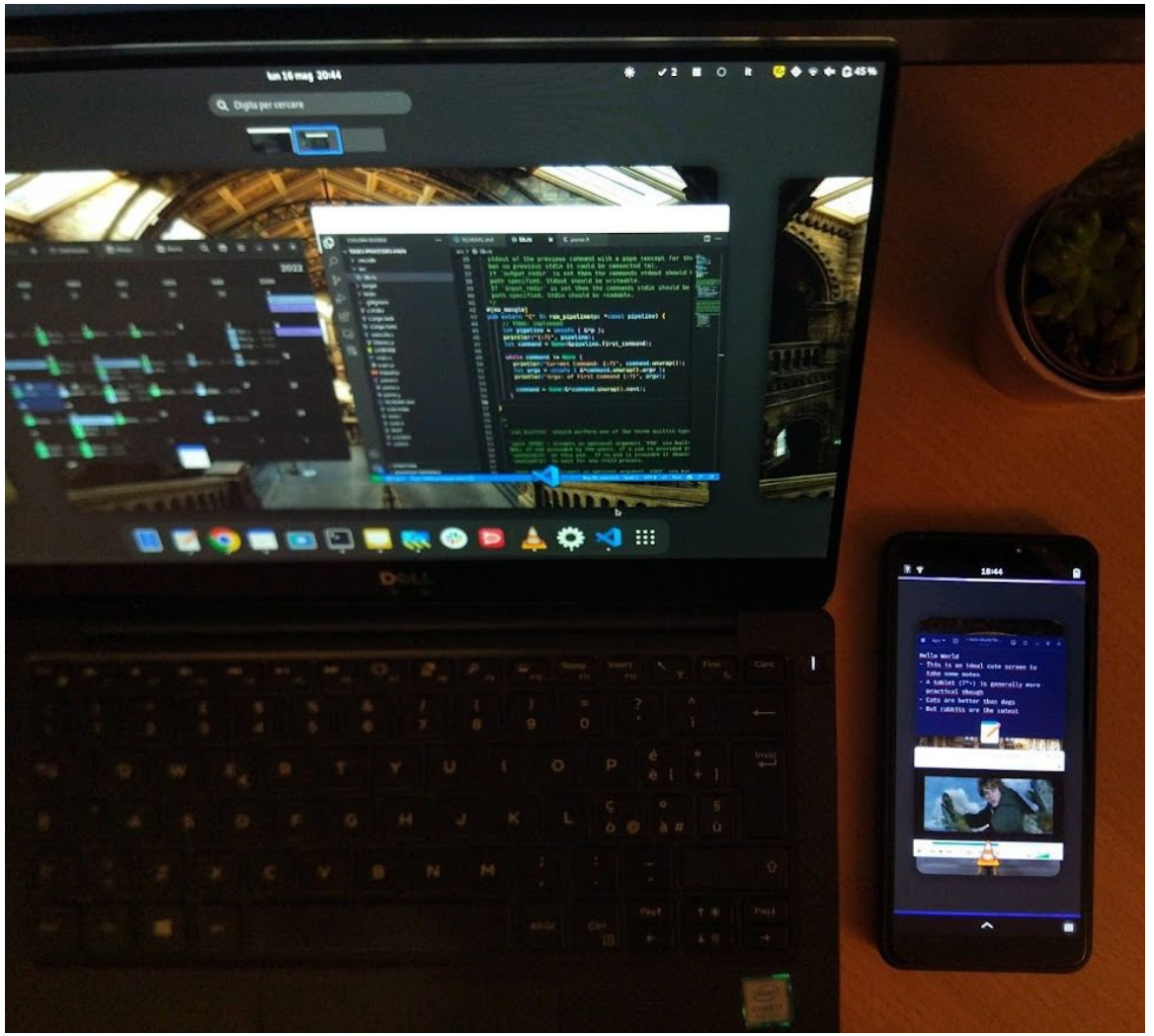
...multiple *bidirectional* virtual mirrors?



Each device should be able to **choose its role**, as a streamer or receiver, at runtime.

Timeline, so far

- 2020: GNOME 40 introduces “Headless native backend and virtual monitors”
  - https://gitlab.gnome.org/GNOME/mutter/-/merge_requests/1698
- May, 2022, first prototype: “Using a Linux phone as a secondary monitor”
  - https://tuxphones.com/howto-linux-as-second-wireless-display-for-linux/
- Nov 2023: first Mirror Hall beta
  - https://fosstodon.org/@tuxdevices/111454321215302030
- Sep 24: First release!
  - “Mirror Hall: peer-to-peer screen sharing between Linux devices” https://notes.nokun.eu/post/2024-09-22-mirrorhall/

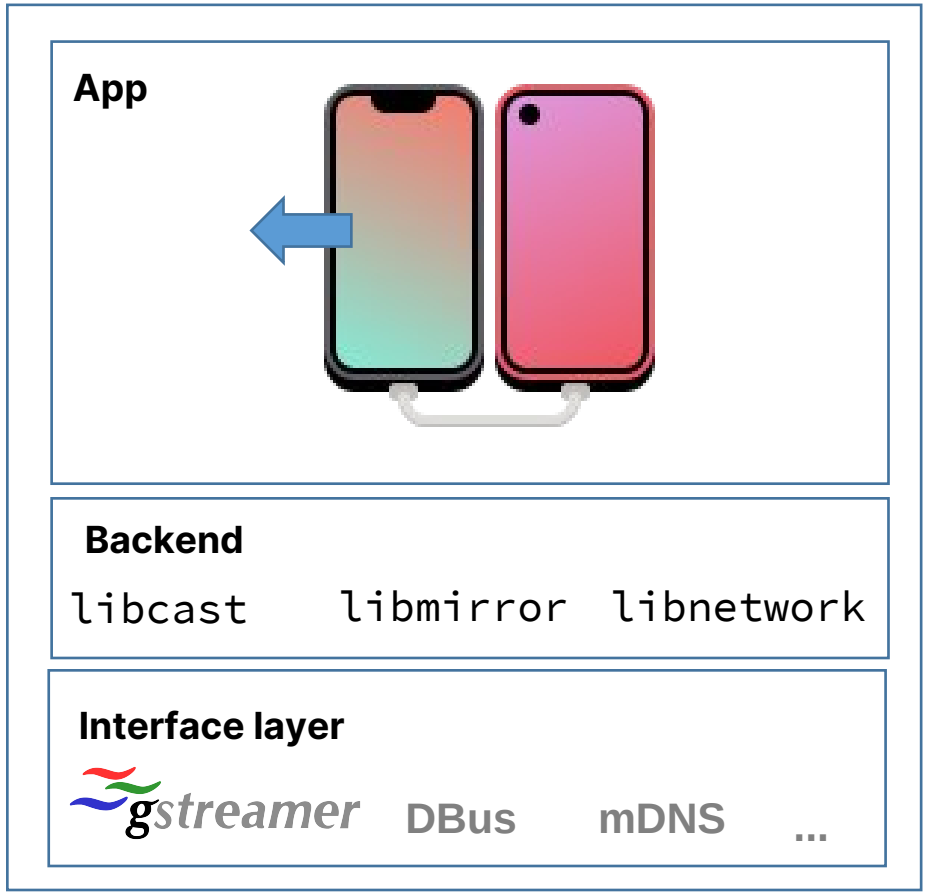


(Mirror Hall window)

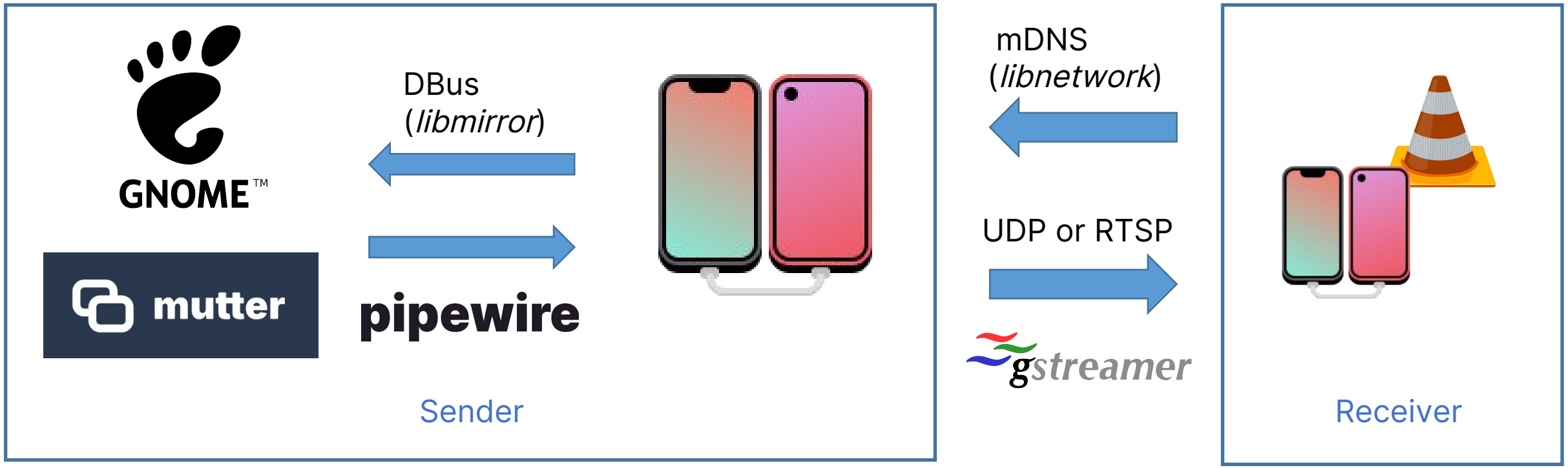
How?

Flatpak

- **MirrorHall** — player/streamer app
  - Adw+Gtk4+custom widgets (player, etc.)
- `libmirror` — creates virtual displays
  - Detects desktop environment
  - Uses D-Bus (for now) to create virtual sink and record it using a PipeWire handle
- `libcast` — streams video over the network
  - Generates the fastest pipelines for video streaming using available hardware accelerators on the host (i.e. GPUs)
    - Intel (vaapi), Qualcomm (venus), Broadcom...
  - Handles network transmission also via GStreamer
- `libnetwork` — handles network communication
  - Advertises Mirror Hall instance on local networks using mDNS (a bit like Chromecast/Airplay/...)
  - Keeps track of health of stream (WiP)
  - Note: the **video** network stream (UDP) is not handled by libnetwork, but offloaded to libcast/gstreamer directly



How?

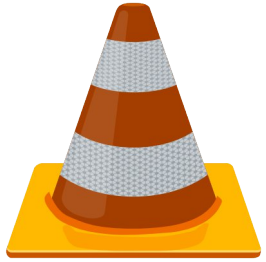

GNOME™
mutter
DBus
(*libmirror*)
pipewire
Sender
mDNS
(*libnetwork*)
UDP or RTSP
gstreamer
Receiver

Bonus: **Retrocompatible Mirroring**

`$ mirrorhall cast`

RTSP

libcast + CLI



`$ gst-launch ...`

so you can use Mirror Hall (somewhat painfully) on clients without Mirror Hall installed

How to build Up a Pipeline

How To: Virtual sinks

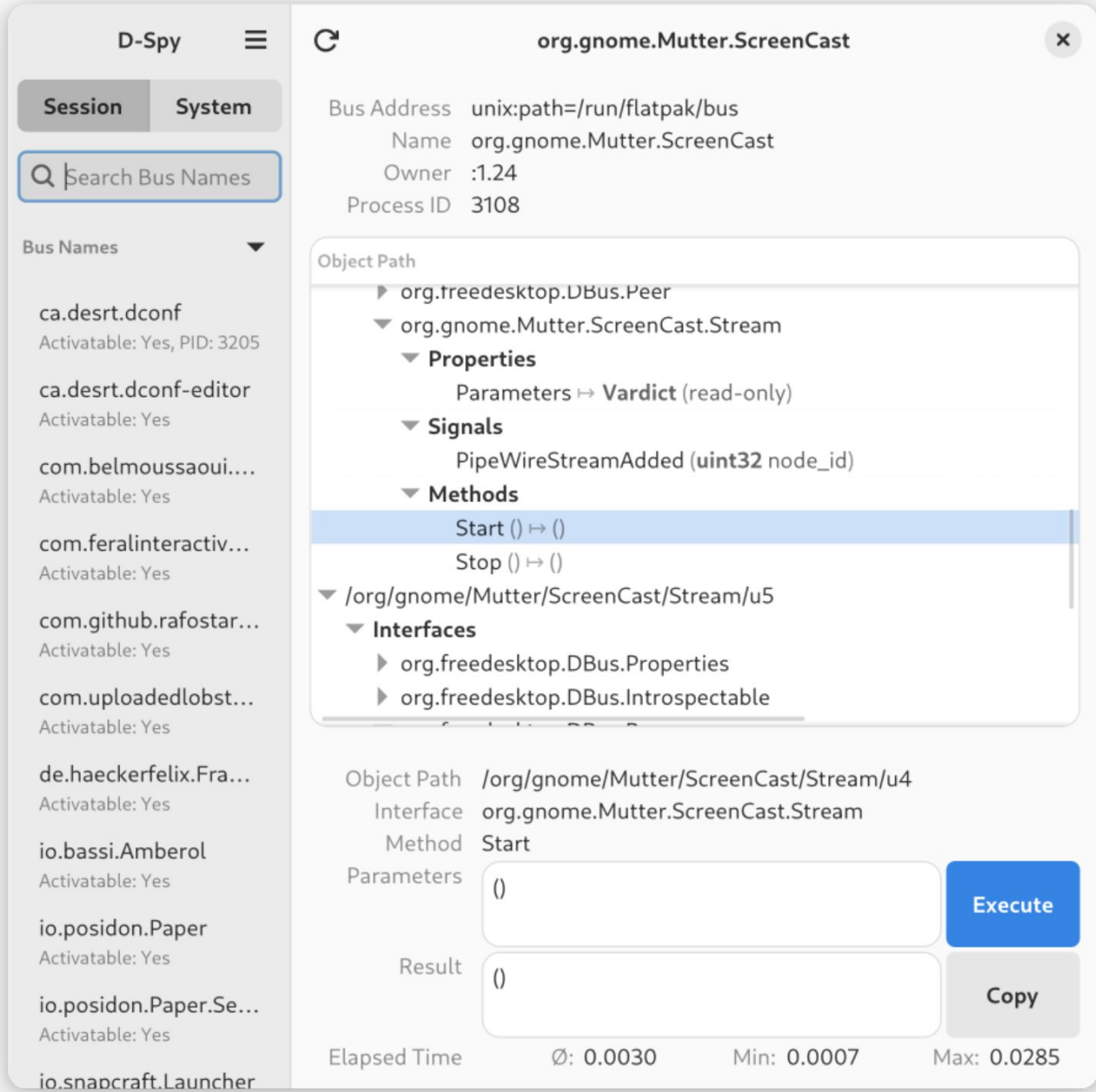
- We won’t talk about mDNS, UDP, health check, etc.
  - …sort of boring
- *libmirror* only supports Mutter
  - Other DEs don’t expose virtual sink APIs yet?
  - Expanding *libmirror* to support them should be quite easy!
- Demo scripts:
  - https://gitlab.com/tuxphones/side-displays
  - https://gist.github.com/louiecaulfield/8688a4dfe59d4f6ec30038be693f7ccf

How To: Virtual sinks

- No interaction with Wayland / kernel: **Mutter** can create a virtual backend for us
- Set of D-Bus calls to Mutter's screencast APIs:
  - **`/org/gnome/Mutter/ScreenCast -> CreateSession`**
    `-> Returns stream name: '/org/gnome/Mutter/ScreenCast/Session/u{x}'`
  - **`/org/gnome/Mutter/ScreenCast/Session/u{x} -> RecordVirtual ({})`**
    `-> Returns stream path: '/org/gnome/Mutter/ScreenCast/Stream/u{x}'`
    - **`Start() -> call after to start the session on the stream`**
  - **`/org/gnome/Mutter/ScreenCast/Stream/u{x}`**
    - **`Create listener on signal: PipewireStreamAdded ->`** `get PipeWire stream ID`

    ```
    $ dbus-monitor --session "type='signal',interface='org.gnome.Mutter.ScreenCast.Stream'"
    ```
  - Then call **Start ()** on session…

    -> PipeWire stream will show up in the event handler!


D-Spy
Session
System
Search Bus Names
Bus Names
ca.desrt.dconf
Activatable: Yes, PID: 3205
ca.desrt.dconf-editor
Activatable: Yes
com.belmoussaoui....
Activatable: Yes
com.feralinteractiv...
Activatable: Yes
com.github.rafostar...
Activatable: Yes
com.uploadedlobst...
Activatable: Yes
de.haeckerfelix.Fra...
Activatable: Yes
io.bassi.Amberol
Activatable: Yes
io.posidon.Paper
Activatable: Yes
io.posidon.Paper.Se...
Activatable: Yes
io.snapcraft.Launcher
org.gnome.Mutter.ScreenCast
Bus Address unix:path=/run/flatpak/bus
Name org.gnome.Mutter.ScreenCast
Owner :1.24
Process ID 3108
Object Path
org.freedesktop.DBus.Peer
org.gnome.Mutter.ScreenCast.Stream
Properties
Parameters ↦ Vardict (read-only)
Signals
PipeWireStreamAdded (uint32 node_id)
Methods
Start () ↦ ()
Stop () ↦ ()
/org/gnome/Mutter/ScreenCast/Stream/u5
Interfaces
org.freedesktop.DBus.Properties
org.freedesktop.DBus.Introspectable
Object Path /org/gnome/Mutter/ScreenCast/Stream/u4
Interface org.gnome.Mutter.ScreenCast.Stream
Method Start
Parameters
()
Execute
Result
()
Copy
Elapsed Time Ø: 0.0030 Min: 0.0007 Max: 0.0285

How To: Streaming

- Once we have the PipeWire stream object, we can send it over the network via GStreamer:
  - The source (**pipewiresrc**) feeds the incoming stream to the GStreamer pipeline
  - The encoder (**x264, libav, openh264...**) transforms the stream into the desided format (H264, H265, VP8, ...)
  - The payload-encoder (**rtph264pay**) segments the stream into transmittable packets
  - The sink (**udpsink, rtspsink, autovideosink**) plays the result or transmits it over the network
  - Queues add buffering (and improve stability)

```
$ gst-launch-1.0 pipewiresrc path=110
        ! video/x-raw,width=1280,height=720
        ! queue
        ! x264enc
              tune=zerolatency bitrate=6500
              speed-preset=faster ! queue
        ! rtph264pay
        ! udpsink host=a.b.c.d port=6906
```

Or, to simply play the PipeWire stream we obtained...

```
$ gst-launch-1.0 pipewiresrc path=110
        ! video/x-raw,width=1280,height=720
        ! videoconvert ! queue
        ! autovideosink
```

How To: Receiving

The other way around...

```
r@eowyn ~> mirrorhall sink 1234

Mirrorhall CLI - version 0.1.1
Tip: run with GST_DEBUG=3 for debugging output
Sink started on port 1234 - press Ctrl+C to stop

Best decoder: avdec_h264
Tip: You can use this command to replicate the pipeline outside of Mirror Hall.
```

```
$ gst-launch-1.0
        udpsrc port=1234 ! queue !     <- Accept UDP stream on port 1234
        rtph264depay ! queue !         <- Extract video from RTP packet
        avdec_h264   ! queue !         <- Decode H.264 using best decoder
        [... convert / parse ... ]     <- Not required for auto-converted pipeline
        videoconvert !                 <- Auto-convert to a player-accepted format
        autovideosink                  <- Play video using any available UI sink
```

All About That Latency

- *libcast* is an accelerated pipeline generator
  - Basically a database that generates a compatible pipeline for devices using Qualcomm (ARM) venus, Intel/AMD (VAAPI), or known encoders like libav, openh264, and x264 with custom profiles
  - Should prioritize zero-copy / stateless in the future
- UDP vs. TCP
  - Latency is *considerably* lower at the expense of video artifacts when connection degrades
- Cap on stream quality (FPS and resolution)
  - We cannot control video quality “live” using UDP
- Try to do minimal encoding work
  - Tweak X264, openh264, libav profiles for simplicity
  - Optimized for **speed over precision** (i.e., temporary artifacts may appear if the connection is weak)

Limitations

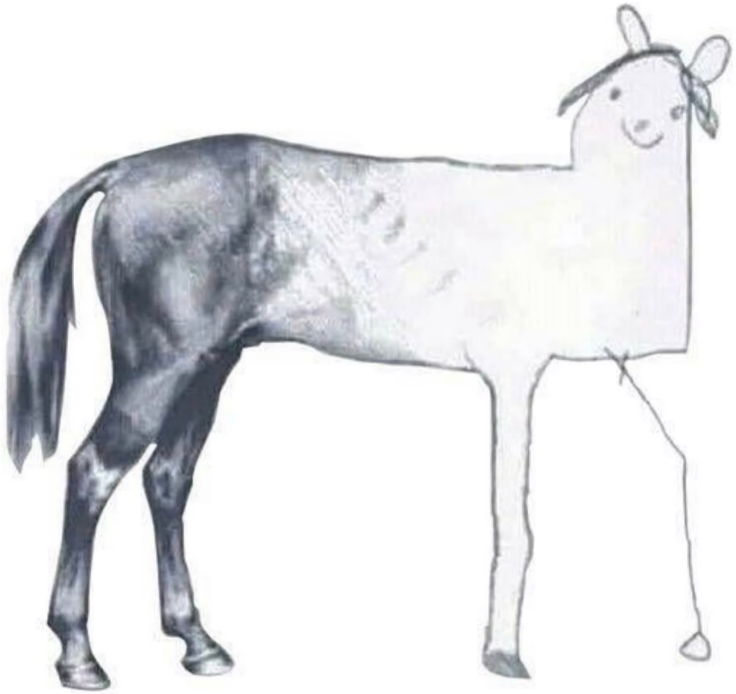
- MirrorHall requires UDP traffic to flow on ports 6900 to 6999
  - The port is randomized to allow multiple instances on the same host
  - Currently, hole-punching via Flatpak is not really an option

iptables:
$ sudo iptables -A INPUT -p udp --dport 6900:6999 -j ACCEPT
$ sudo iptables -A OUTPUT -p udp --sport 6900:6999 -j ACCEPT

firewalld (Fedora):
$ sudo firewall-cmd --permanent --add-port=6900-6999/udp
$ sudo firewall-cmd --reload

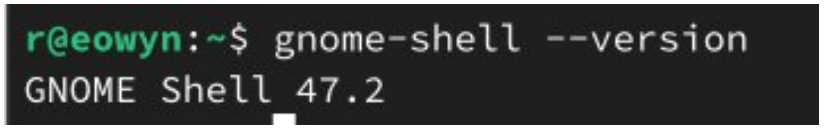
ufw (Ubuntu):
$ sudo ufw allow 6900:6999/udp

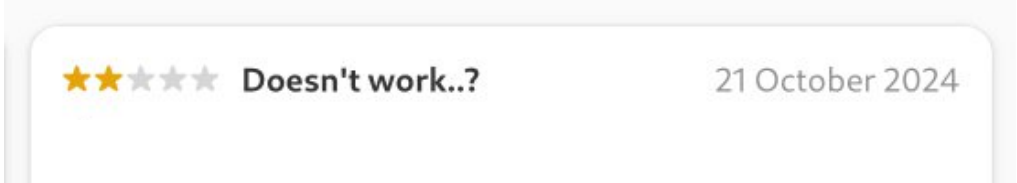
nftables (postmarketOS):
$ sudo nft add rule inet filter input udp dport 6900-6999 accept
$ sudo nft add rule inet filter output udp sport 6900-6999 accept

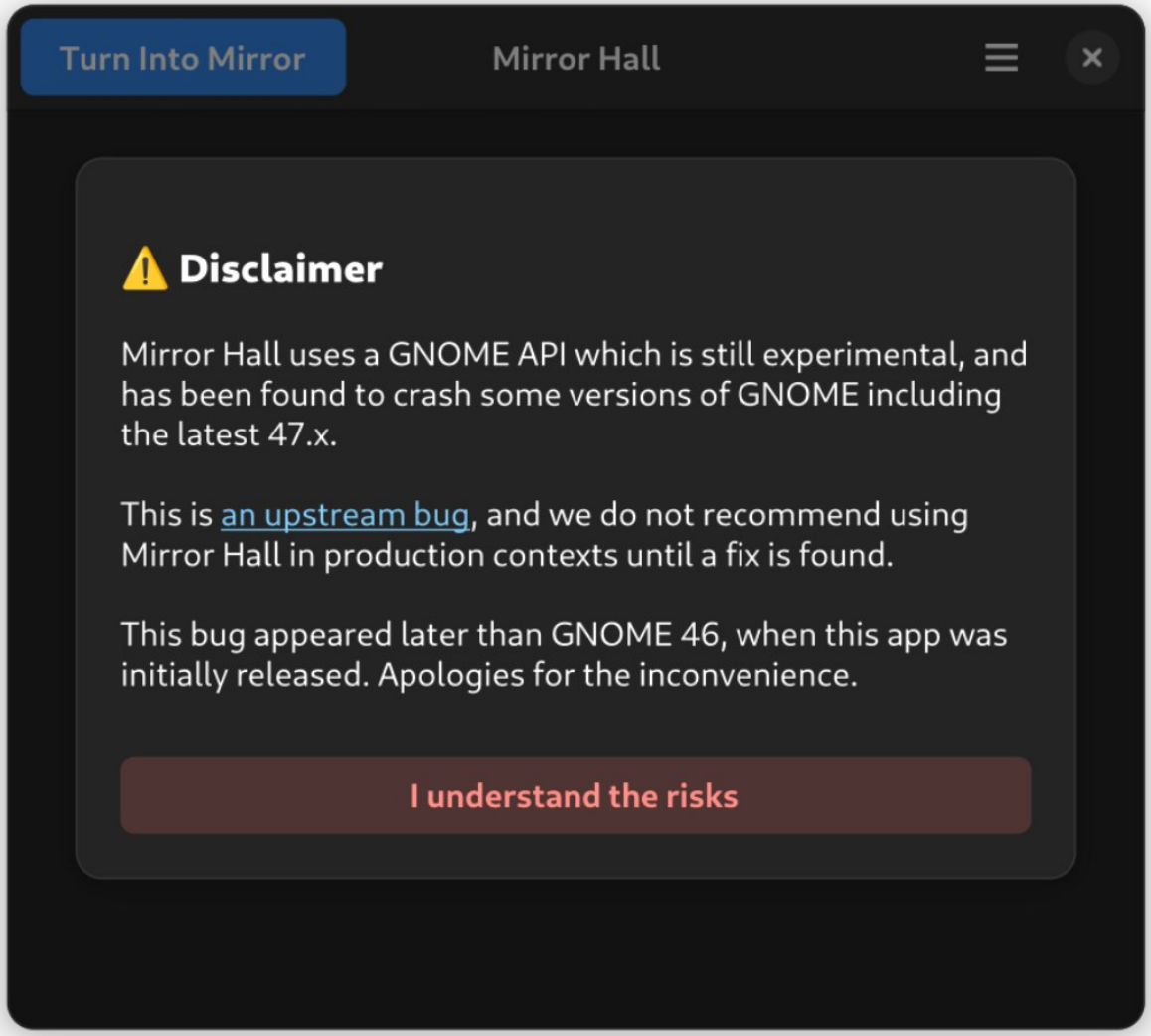


Limitations pt. 2

- Newer versions of GNOME **crash** when closing Mirror Hall - bad release timing :D
  - Mutter 43.x, 47.0, 47.1 are affected
  - 47.2 *seems* to work fine so far
  - Try at your own risk :)
- Flathub's version is slightly slower as it does not include proprietary encoders
- Some other crashes esp. on ARM
  - 0.1.1 fixed some — testers needed!





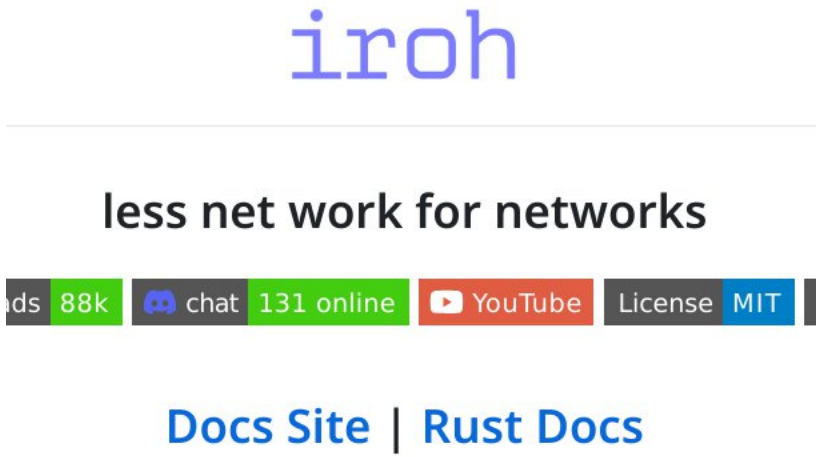


Next steps

- **Encryption** and stability
  - Insecure raw UDP H.264 for now
  - No existing solution within GStreamer (?)
- Split up app and protocol layers, adding UDP hole-punching

—> Ideally: Rust + `iroh`

- Add mirroring of input methods
  - e.g., for the use case of signing a document using Wacom-enabled tablet
  - Maybe: proxy input events directly?
- Even Faster
  - Zero-copy + stateless components



Conclusion

- We're at 0.1.1. There's still a **long** way to go...
  - Divide into smaller components, improve transmission stability, and make it work upstream (i.e., not GNOME-only)
- Thanks to all who supported me!
  - Sonny Piers, Caleb Connolly, Jonas Dressler, Tobias Bernard, Robert Mader, Rafał "rafostar" Dzięgiel, ...
- Looking for collaborators!
  - Extend to other platforms (KDE, Sway) / protocols / hardware (RPi, ...)
- Keep in touch?
  - DM me on Mastodon: @tuxdevices
  - Write me directly — r@nokun.eu
  - Let's meet in Berlin!

Attribution

References. (1) Schilit, Adams, et al., "The PARCTAB mobile computing system," Proceedings of IEEE 4th Workshop on Workstation Operating Systems. WWOS-III, Napa, CA, USA, 1993, pp. 34-39

Images. p.2: see (1), p.3: Myrabella / Wikimedia Commons / CC BY-SA 3.0; Apple Sidecar (apple.com/de/newsroom/2019/06/apple-previews-macos-catalina/); p.4: tuxphones.com, p.22: http://www.supertuxkart.at/page3/page3.html, p.16: modified from the cover of A. Malm, *How To Blow Up A Pipeline,* Verso Books

Artwork. The Mirror Hall icon was designed by Tobias Bernard.

More Links + Q&A

Chat rooms (join us!)
@mirrorhall:gnome.org | t.me/MirrorHallApp

Me (email) / TuxPhones (Mastodon 🐘)
@tuxdevices@fosstodon.org | r@nokun.eu

Mirror Hall 0.1.0 — Technical Deep Dive
notes.nokun.eu/post/2024-09-22-mirrorhall/

GitLab — Mirror Hall
gitlab.com/nokun/mirrorhall