Intelligence at the Speed of Light™

SDK Internals and Advanced Topics

Cepton Webinar Series #4

2022-05-04

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What type of device is Cepton lidar?

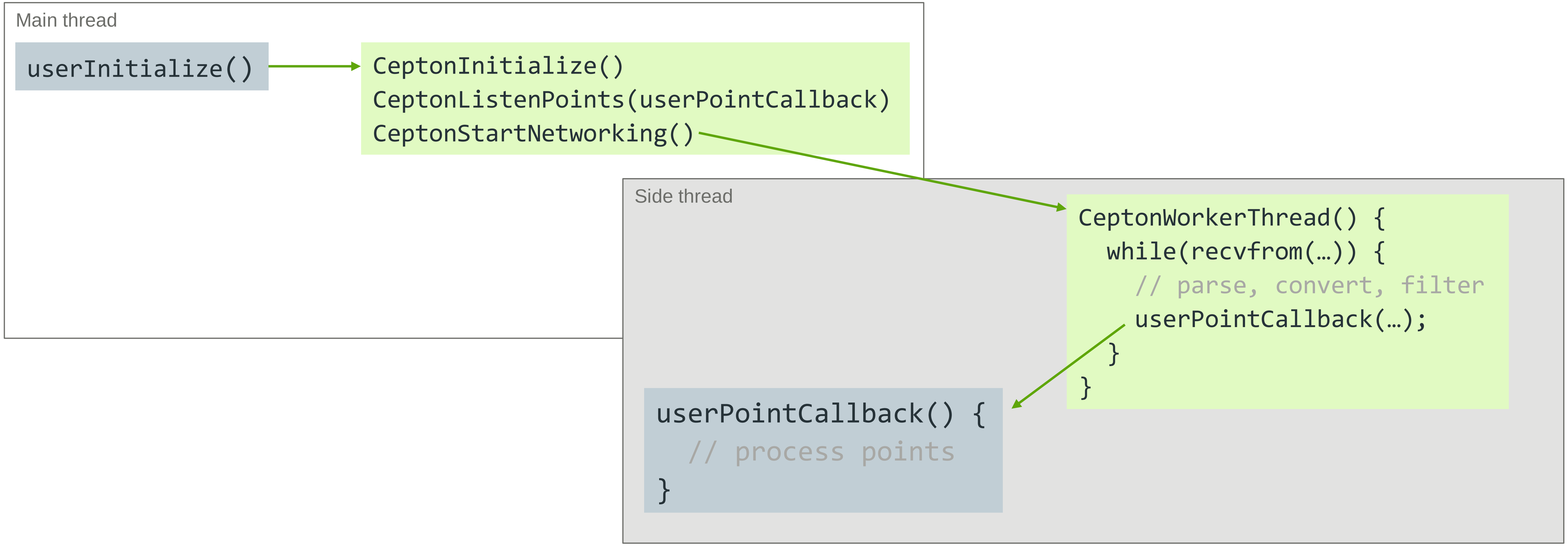
Important aspects of lidar that determine how SDK functions

- Lidars are connected through ethernet cables
  - All data coming from sensor to host are UDP packets
  - Ethernet devices do not need “driver”. User applications can use lidars directly (with SDK)
- Lidars are outgoing-only passive devices
  - SDK only listens, there is no handshake between lidar and host computer.
  - Exception: Device configurations and firmware updates. These are only used during setup or maintenance.
- Things lidar devices do not do:
  - No trigger for action, no dynamic area-of-interest (AOI).
  - No buffer for frames: Frame buffer exist on host computer. Lidars only do streaming-mode.
  - No connection: Lidars default to broadcast mode. Can be changed to multicast or unicast.

How does ethernet programming work?

UDP programming: `socket()` → ~~`sendto()`~~`/recvfrom()`

- Simplest UDP program call `recvfrom()` which is blocking. Not suitable for SDK
- In SDK, we use a thread to do the blocking receive. This is standard practice in network programming (e.g., asio)



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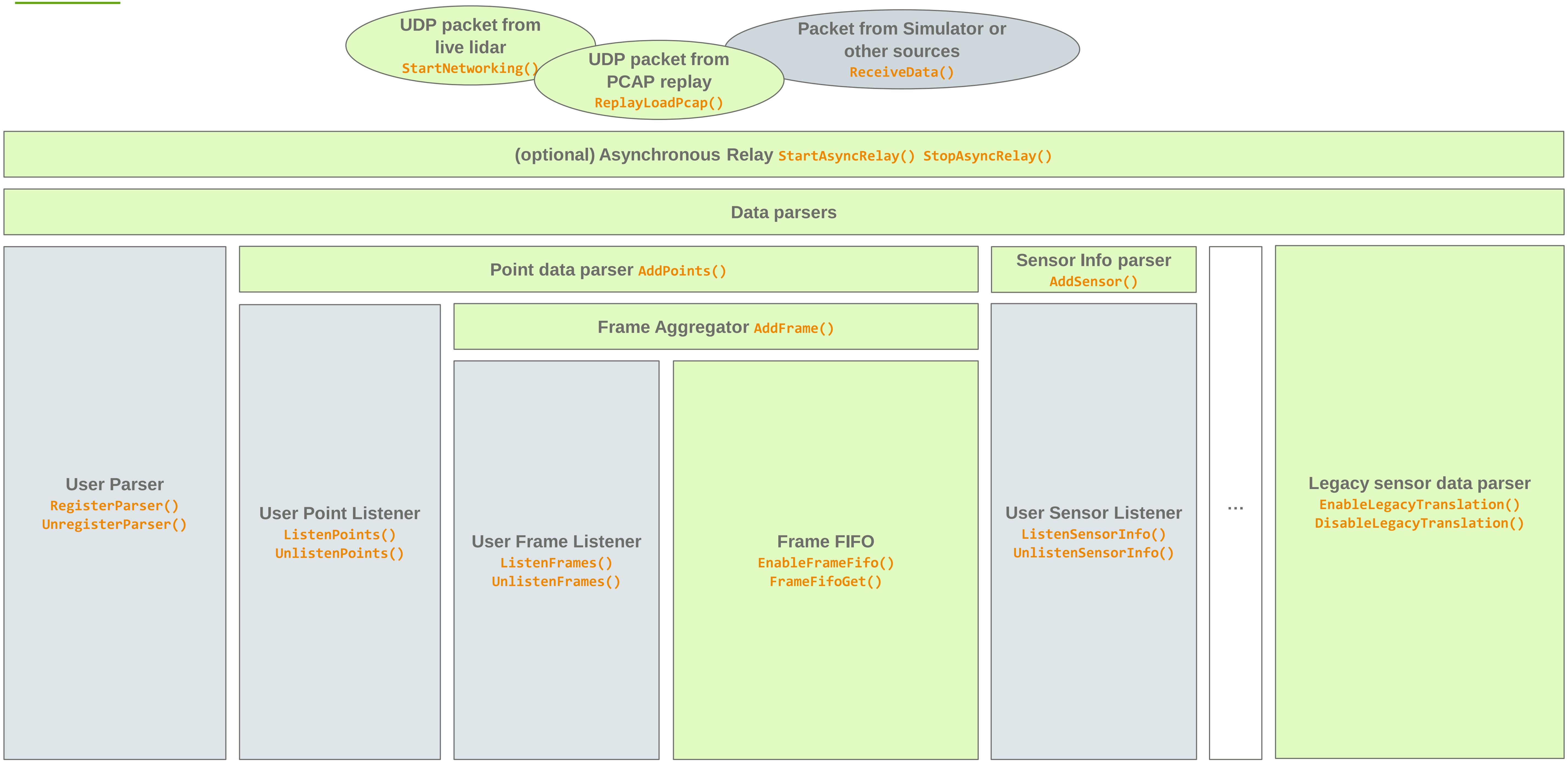
Cepton SDK Architecture



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Direct Frame FIFO

CEPTON

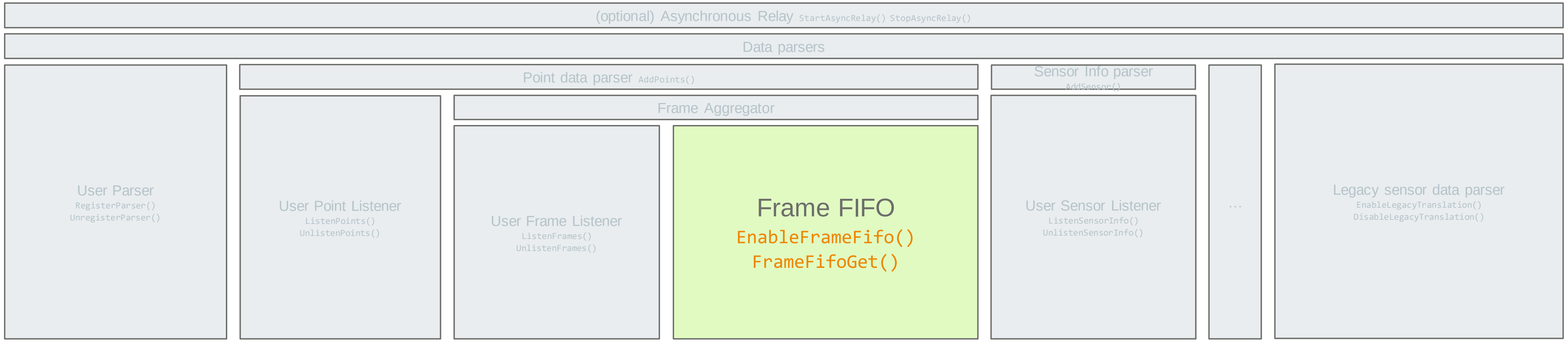
Ideal simple API to work with lidars: `GetFrame()`

- Python and MATLAB APIs are based on this.
- Buffered frame in FIFO: `EnableFrameFifo(…, int nFrames);`
- Frame FIFO are implemented as an independent module using `ListenFrames()`
  - Register itself as a frame listener
  - Allocate FIFO buffers at enable time
- Copy-less and allocation-free design: Concept of “get” and “release”
- Blocking and non-blocking behavior:
  - Both producer and consumer can block when FIFO is full or empty

Python offline processing sample:

```
# Loop until pcap replay is finished and fifo drained
while not (sdk.ReplayIsFinished() and sdk.FrameFifoEmpty()):
    frame = sdk.FrameFifoGetFrame(timeout=2000) # 2000 ms

    if frame is not None:
        print("get frame: {}, size: {}, start timestamp: {:.6f}s durat
            frame_count, len(frame.flags), frame.timestamps[0]*1e-6, (
        frames.append(frame)
        frame_count += 1
        sdk.FrameFifoRelease()
```



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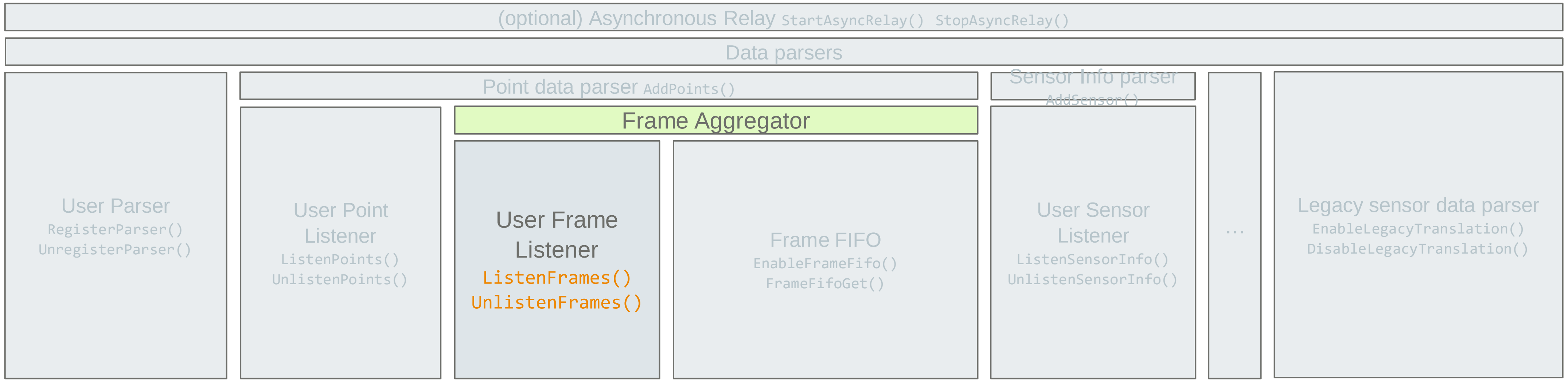
Frame Aggregation

- What is a frame: A sequence of measurements that covers the entire field of view.
- Sensor hardware knows where a frame starts and ends. It uses per-point *frame parity* bit to indicate even/odd frames.
- SDK keeps all points in a buffer until parity changes. It issues a *frame callback* when that happens.
- SDK-side aggregation mode:
  - Natural mode: Use sensor's frame boundary, variable size, fixed pattern.
  - Timed mode: A fixed time slice of the streaming data. Can use to aggregate for longer or shorter time.
- Frame aggregation is implemented as an independent module using `ListenPoints()`
- Aggregated frames are served through callbacks registered with `ListenFrames()`
- Frame boundary (overlap) in natural mode



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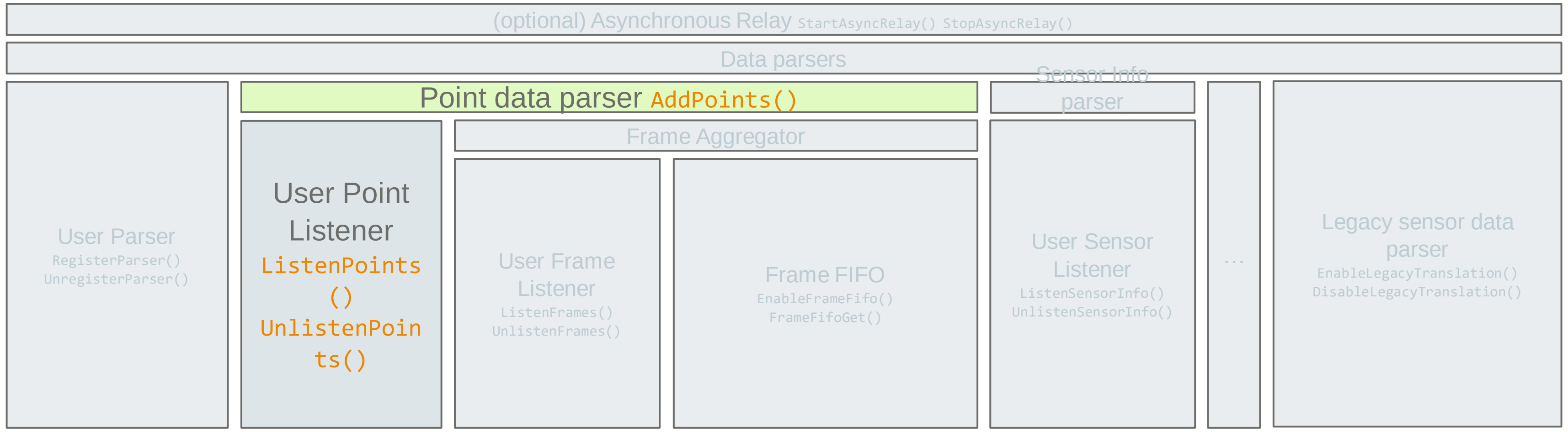
Point Data

- Point data comes directly from sensor in modern sensors
- Concept of *stride* to be future compatible
- Reflectivity representation: 0-100%, then 101-255 with exponential lookup table
- Legacy sensors or encrypted data goes through different parsers
- Explanation of the point flags
- Point data parser module:
  - Point data parser takes UDP packet and convert them to points.
  - Points are fed into every point listeners.
  - Direct call of `AddPoints()` can be used to inject points into SDK pipeline

SDK's point data structure:

```
enum {
  CEPTON_POINT_SATURATED = 1 << 0,
  CEPTON_POINT_LOW_SNR = 1 << 1,
  CEPTON_POINT_FRAME_PARITY = 1 << 2,
  CEPTON_POINT_FRAME_BOUNDARY = 1 << 3,
  CEPTON_POINT_SECOND_RETURN = 1 << 4,
  CEPTON_POINT_NO_RETURN = 1 << 5,
  CEPTON_POINT_NOISE = 1 << 6,
};

struct CeptonPoint {
  int16_t x;
  uint16_t y;
  int16_t z;
  uint8_t reflectivity;
  uint8_t relative_timestamp;
  uint8_t channel_id;
  uint8_t flags;
};
```



Sensor's point data format:

Offset	Field	Size	Unit	Range	Description
0	X	2	0.5cm	-163.840m to 163.835m	X coordinate
2	Y	2	0.5cm	0 to 327.68m	Y coordinate
4	Z	2	0.5cm	-163.840m to 163.835m	Z coordinate
6	Reflectivity	1	%	0 to 255	Reflectivity
7	Timestamp	1	us	0 to 255	Time difference from the point before
8	Channel	1		0 to 63	Channel ID
9	Flags	1			Flags
10+	Internal				When PointSize > 10, these are internal data

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Packet Parsers

What's going through on the network?

- Point data
  - Cepton point clouds
  - Legacy point clouds (from older sensors)
  - Encrypted or signed point data
- Other data from sensors
  - Sensor information: Status, firmware version, etc.
  - Error reporting
- Other sensors
  - Camera
  - Other vendor's lidars

(Cepton network communication specificiation documents are available for latest sensor generations)

What can you do with SDK's raw packet parser?

- Leverage SDK's networking code with data callback
- Seamlessly handle different data formats
  - This is how `EnableLegacyTranslation()` works
  - Add support for other network devices in the same code base.
- Seamlessly inject data into the perception pipeline
  - Directly call `ReceiveData()` to emulate live sensor
  - This is how PCAP replay is implemented
  - Can integrate with frameworks where networking is not directly exposed. (NVIDIA Driveworks, e.g.)

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Packet Parsers (continued)

How to use packet parsers?

- This is not common, only advanced applications need to parse packets directly.
- User code and SDK internal modules (like legacy connector) register parser callbacks:
  - `RegisterParser()` `UnregisterParser()`
- Each UDP packet received by SDK is passed into every parser callbacks until it is "consumed" by one.
  - Parsers use return values to indicate if the data should be passed on or not.
- User code and SDK's replay module can use `ReceiveData()` to directly inject data into this parser chain.
- Existing SDK parsers:
  - Point data parser (enabled by default)
  - Sensor info parser (enabled by default)
  - Serial data parser (enabled when `ListenSerialLines()` is called)
  - Legacy connector parser (enabled when `EnableLegacyTranslation()` is called)

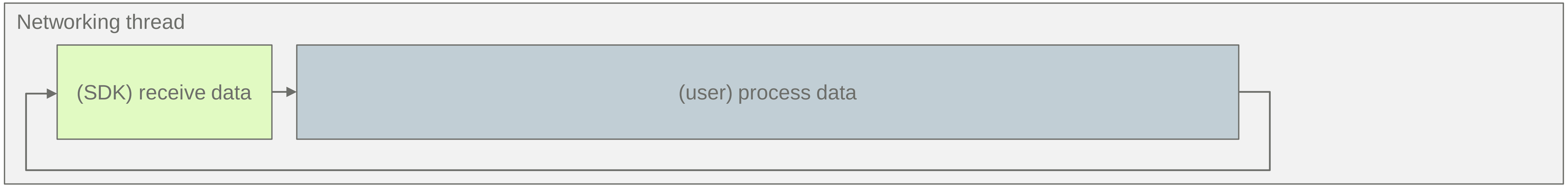
Asynchronous Relay

Problem: UDP is not tolerant of latency.

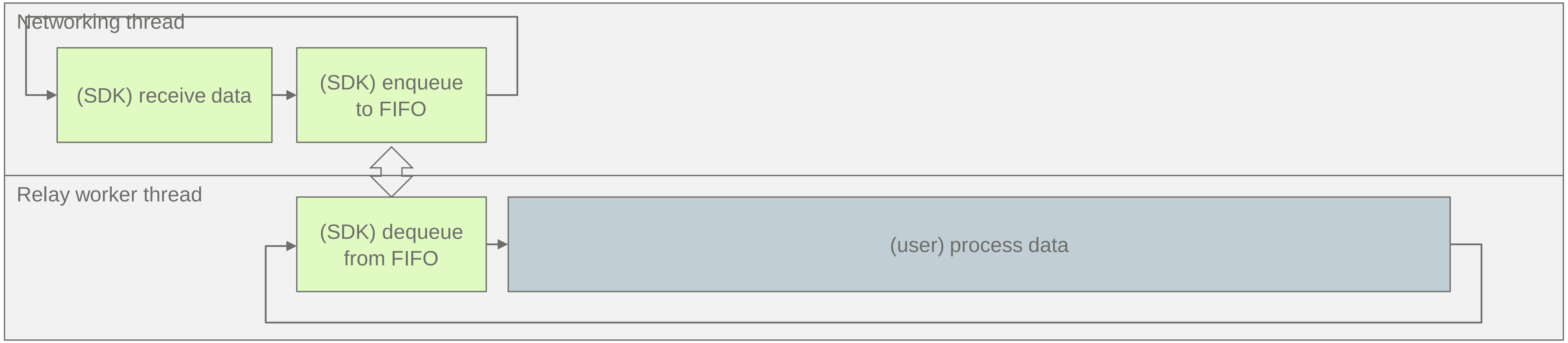
- User callback routines (point or frame) is run directly on networking thread with unbounded delays
- It is not desirable to limit processing time, neither is losing data from sensor.

Solution: Decouple UDP receive code from user processing code with a producer-consumer FIFO:

Before:



After:



Asynchronous Relay (continued)

- SDK’s asynchronous relay is a middleware sits between network data and all the parsers.
- SDK’s asynchronous relay is transparent: You can enable and forget.
- Relay FIFO helps when there are uneven processing times that are fast enough on average.
- When relay FIFO is full, data will still get lost. If average processing time is slower than incoming data, FIFO won’t help.
- Like other features in SDK: asynchronous relay is off by default. It must be explicitly enabled.
- When enabled, asynchronous relay allocates all the FIFO buffers and starts a new thread. There is no other allocation or additional copying during the operation.

Capture Replay Facility

Replay functionalities

- Load and play multiple .pcap files, control each independently: `ReplayLoadPcap()`
- Support pause/resume/step/seek: `ReplayPause()` `ReplaySeek()` etc.
- Replay speed can be controlled: `ReplaySetSpeed()`
- Special “full speed” mode for off-line processing without delay

Replay internals

- Replay facility is implemented as an independent module using `ReceiveData()`
- Each pcap file being replayed creates its own thread for replay
- Indexing of pcap
  - Each pcap file being replayed may optionally create an indexing thread: `ReplayGetIndexPosition()`
  - Index records are not persisted for .pcap files
- Replay can coexist with live sensor or other data sources.

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Brief Summary

SDK architecture

- Features in SDK are like Lego blocks with all interfaces exposed for customization.
- SDK is doing very little work other than plumbing and buffering.
- SDK is designed to do no copying (other than frame aggregation) and no allocation during perception inner loop.

Interact with SDK at different levels

- Direct frames from FIFO
- Frame callbacks
- Point callbacks
- Raw data callbacks

Ways to use SDK

- Online processing with live sensor
- Offline processing with PCAP
- Mix and match different things with direct data injection

Advanced Topics

- Sensor self announcement
  - Cepton sensor broadcast a “sensor info” data packet regularly (every 0.5-1 second)
  - Sensor info packet contains both static info (serial number, revision, firmware version, features etc.) and diagnostic info (temperatures, voltages etc.)
  - Caveat: Point data can arrive *before* sensor info.
- SDK binding mechanism
  - Operating system native dynamic linking (C/C++/Rust)
  - Python/Matlab integrations and language-native APIs.
  - Foreign function interfaces for JavaScript/Ruby etc.
- How legacy connector works and some FAQs on legacy hardware
  - For Vista-P sensors, CPU is used to perform some calibration calculations that can be heavy.
  - Legacy connector relies on the old SDK dynamic library to function.
- Details in handling multiple sensors
  - `CeptonSensorHandle` is the unique identifier of sensors.
  - For live sensors `CeptonSensorHandle` is the source IP address.

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Future Topics For Webinar

- Cepton MMT and scan pattern.
- Cepton's perception system and CR file.
- Physics of lidar sensors and common misconceptions

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Resources

- Developer Center (https://developer.cepton.com coming soon…)
  - This and all other webinars
  - Download SDK package
  - Download Cepton Viewer executable
- Official cepton.com
- JOB postings: LinkedIn and Handshake

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