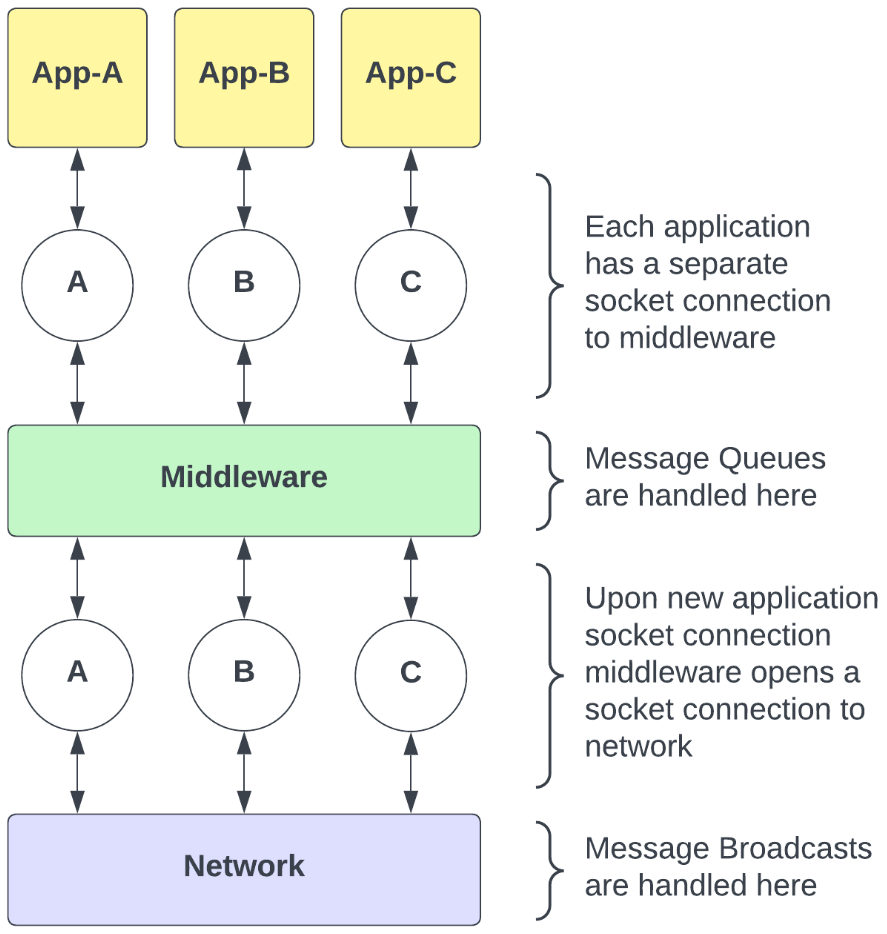
Architecture



App-A
App-B
App-C
A
B
C
Each application has a separate socket connection to middleware
Middleware
Message Queues are handled here
A
B
C
Upon new application socket connection middleware opens a socket connection to network
Network
Message Broadcasts are handled here

- `socket.io-client:` Used for connecting to Socket.IO servers from a Node.js client.
- `express:` Used for building web applications and APIs in Node.js.
- `http:` A core module in Node.js used to create an HTTP server.
- `socket.io:` A library for enabling real-time, bidirectional, and event-based communication between web clients and servers using WebSockets or other transports.
- `crypto:` A core module in Node.js used for cryptographic operations. In this project, it's used to generate random UUIDs.

Middleware - The Heart

What happens when a application connects to middleware ?

- When an application connects to the middleware through socket, it creates a new middleware instance which initializes a timestamp, queue to store messages, map to store acknowledgement counts and a socket connection to the network.

- An event listener is set up on the socket object. When the "broadcast_event" event is emitted from the application side, the `broadcast(data)` function will be invoked. This allows the application to use the broadcast functionality provided by the middleware.

```
socketServer.on("connection", (socket) => {
  console.log(`App-${socket.id} Connected to Middleware`);

  // A new middleware instance for every application socket
  const middleware = Middleware(socket);

  // Exposing API so that application can use broadcast of middleware
  socket.on("broadcast_event", middleware.broadcast);

  // Handle disconnection
  socket.on("disconnect", () => {
    middleware.disconnect();
    console.log(`App-${socket.id} Disconnected from Middleware`);
  });
});
```

How can a application send a broadcast message ?

- Application provides a simple to use `send()` function which emits an event called `broadcast_event` to the middleware.
  (Refer to `send()` function in `app.js`)
- When a `broadcast_event` is received / triggered at middleware, The local timestamp is incremented and a JSON structure is formatted which contains all the necessary information. If a normal message is broadcasted the JSON contains the message content and a random id is assigned. If its an acknowledgement, we set ack flag to true and also include the id of the message for which acknowledgement is being sent. Then a `broadcast_event` is emitted to the network.
  (Refer to `broadcast(data)` function in `middleware.js`)
- Upon receiving a `broadcast_event` at network, it emits a `message` event to all the connected middleware sockets. Then the middleware is responsible for handling the message from network and delivering it to respective applications.
  (Refer to `server.js`)

How can a application recieve a message ?

- When the middleware receives a message from the network server, it triggers the `handleIncomingMessage` function. If the incoming message is an acknowledgment, it updates the acknowledgment count in the `acksMap`
- The middleware checks if front message in the queue can be delivered to the application. If the acknowledgement count of the message is equal to total no.of applications then we pop and send the message to application.

```
// Whenever middleware sends message to application
middleSocket.on("message", (data) => {
  // add the message to outputCollector which is an array of all messages recieved at applicati
  outputCollector.push(data.message);
});
```

Psuedo code

1. Sending a broadcast_event from middleware to network

```
function broadcast(data) {
  // Extract properties from data
  const { messageId, message, ack } = data;

  // 1. Increment the local timestamp
  timestamp = timestamp + 1;

  // 2. Prepare the data for broadcasting
  if (ack) {
    // 2a. If it is an acknowledgemnent, ack flag, id of the message being acknowledged
    // application id of the sender, and timestamp of the sender, here sender means the middlewa
    data = {
      ack,
      id: messageId,
      senderAppId: appSocket.id,
      senderTimestamp: timestamp,
    };
  } else {
    // 2b. If it is not an acknowledgement, generate a random id for the message,
    // application id of the sender, timestamp of the sender, and the content
    data = {
      id: randomUUID(),
      senderAppId: appSocket.id,
      senderTimestamp: timestamp,
      message: message,
    };
  }

  // 3. send the data to the network which broadcasts to all the applications
  networkSocket.emit("broadcast_event", data);
}
```

2. Handling incoming broadcasted messages from network at middleware

```javascript
function handleIncomingMessage(data) {
  // 1. Extract message ID, timestamp, ack flag from incoming data
  const { id, senderTimestamp, ack } = data;

  // 2. update the local timestamp
  timestamp = Math.max(timestamp, senderTimestamp) + 1;

  // 3. If acknowledgment received
  if (ack) {
    // 3a. Update acknowledgment count for the message
    if (acksMap.hasOwnProperty(id)) acksMap[id]++;
    else acksMap[id] = 1;

    // 3b. Check if all acknowledgments received for the message on top of queue
    handleDeliverMessage();
    return;
  }

  // 4. If the messsage is not an acknowledgement

  // 4a. Add the data to the queue
  messageQueue.push(data);

  // 4b. Sort the message queue by timestamp and sender ID
  messageQueue.sort((a, b) => {
    if (a.senderTimestamp === b.senderTimestamp) {
      return a.senderAppId.localeCompare(b.senderAppId);
    }
    return a.senderTimestamp - b.senderTimestamp;
  });

  // 4c. Send acknowledgment for the message
  sendAck(id);
}
```

3. Deliver message from middleware to application

```
// This is executed when an acknowledgement is recieved
// Process messages in the queue
function handleDeliverMessage() {
  // 1. Deliver the message from front of queue to app only if all the acknowledgements have bee
  while (messageQueue.length > 0 && acksMap[messageQueue[0].id] == NUM_APPS) {
    // 2. Remove the message ID from acknowledgments map as we no longer need it after sending i
    delete acksMap[messageQueue[0].id];
    // 3. Get and pop the message from the queue
    const data = messageQueue.shift();
    // 4. Deliver the message to the application
    appSocket.emit("message", data);
  }
}
```

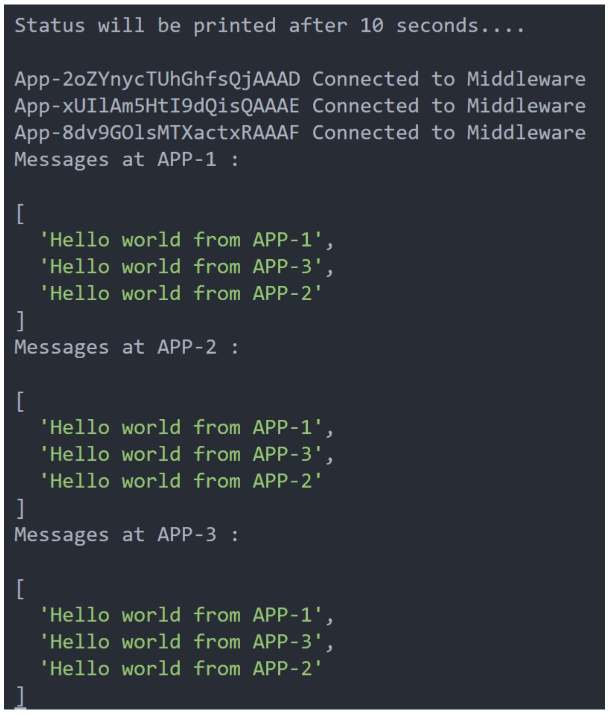
4. Broadcasting message to all middlewares from network

```
socket.on("broadcast_event", async (data) => {
  await randomSleep(1000); // 1. Random delay for sending broadcast messages
  io.emit("message", data); // 2. This message event at middleware triggers handleIncomingMessag
});
```

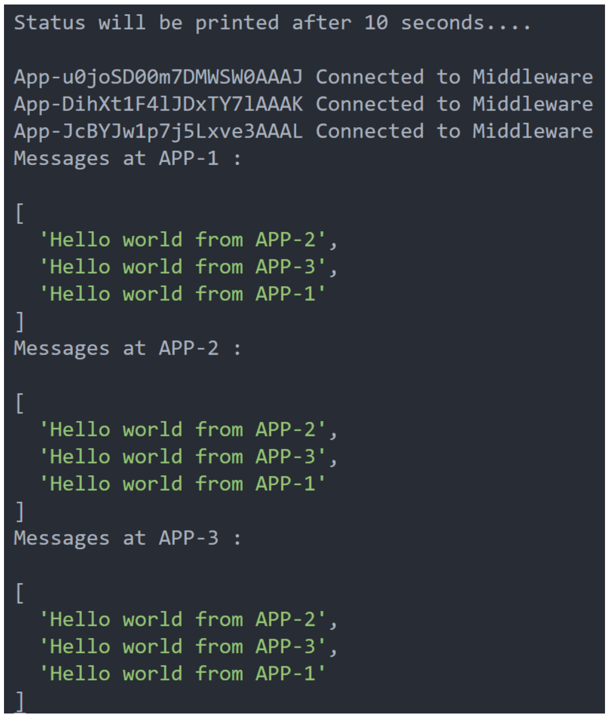
Testing

- Refer `test.js`
- It imports the App class from a file named "app" and the constant NUM_APPS from a configuration file.
- It initializes an array named outputs which will hold the output of each app.
- It iterates NUM_APPS times, creating an instance of the App class for each iteration and passing the corresponding output array.
- It calls the send method on each app instance to trigger the sending of a message.
- It schedules the printing of the outputs array after 10 seconds using setTimeout.
- We can observe the order of messages recieved at every application is consistent.

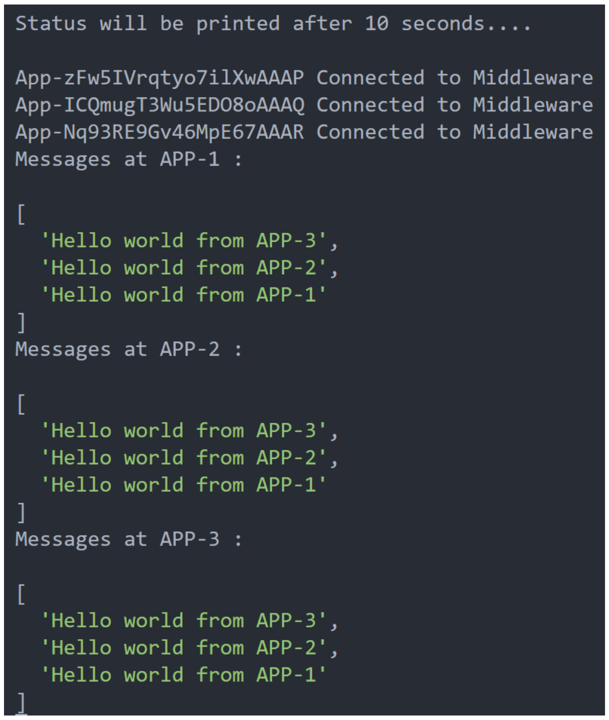
Multiple Test runs with 3 Applications



```
Status will be printed after 10 seconds....

App-2oZYnycTUhGhfsQjAAAD Connected to Middleware
App-xUIlAm5HtI9dQisQAAAE Connected to Middleware
App-8dv9GOlsMTXactxRAAAF Connected to Middleware
Messages at APP-1 :

[
  'Hello world from APP-1',
  'Hello world from APP-3',
  'Hello world from APP-2'
]
Messages at APP-2 :

[
  'Hello world from APP-1',
  'Hello world from APP-3',
  'Hello world from APP-2'
]
Messages at APP-3 :

[
  'Hello world from APP-1',
  'Hello world from APP-3',
  'Hello world from APP-2'
]
```

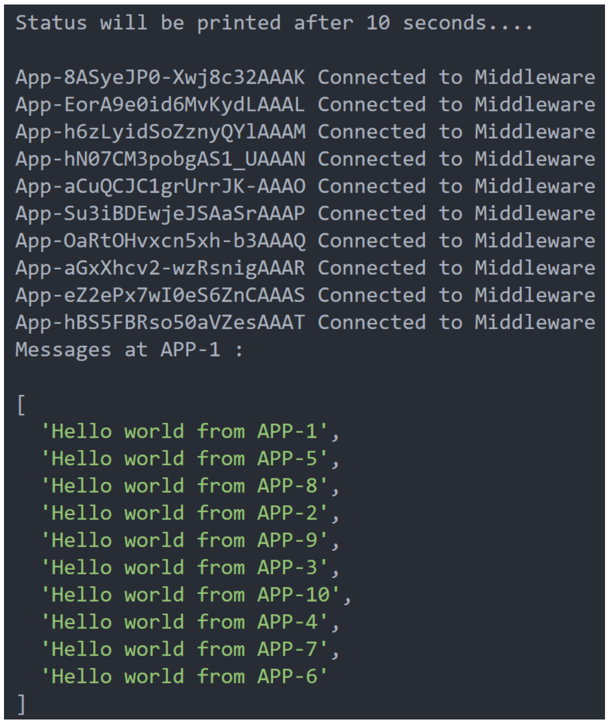


```
Status will be printed after 10 seconds....

App-u0joSD00m7DMWSW0AAAJ Connected to Middleware
App-DihXt1F4lJDxTY7lAAAK Connected to Middleware
App-JcBYJw1p7j5Lxve3AAAL Connected to Middleware
Messages at APP-1 :

[
  'Hello world from APP-2',
  'Hello world from APP-3',
  'Hello world from APP-1'
]
Messages at APP-2 :

[
  'Hello world from APP-2',
  'Hello world from APP-3',
  'Hello world from APP-1'
]
Messages at APP-3 :

[
  'Hello world from APP-2',
  'Hello world from APP-3',
  'Hello world from APP-1'
]
```

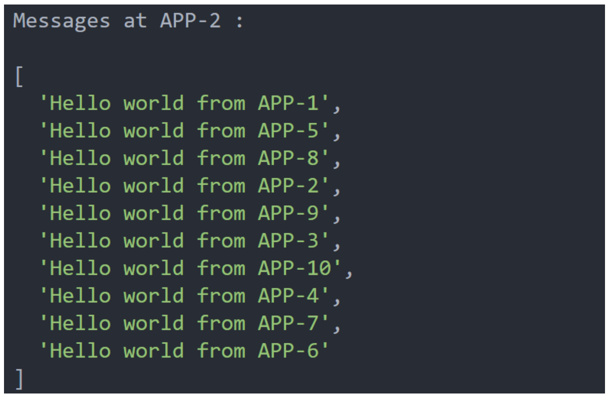


```
Status will be printed after 10 seconds....

App-zFw5IVrqtyo7ilXwAAAP Connected to Middleware
App-ICQmugT3Wu5EDO8oAAAQ Connected to Middleware
App-Nq93RE9Gv46MpE67AAAR Connected to Middleware
Messages at APP-1 :

[
  'Hello world from APP-3',
  'Hello world from APP-2',
  'Hello world from APP-1'
]
Messages at APP-2 :

[
  'Hello world from APP-3',
  'Hello world from APP-2',
  'Hello world from APP-1'
]
Messages at APP-3 :

[
  'Hello world from APP-3',
  'Hello world from APP-2',
  'Hello world from APP-1'
]
```

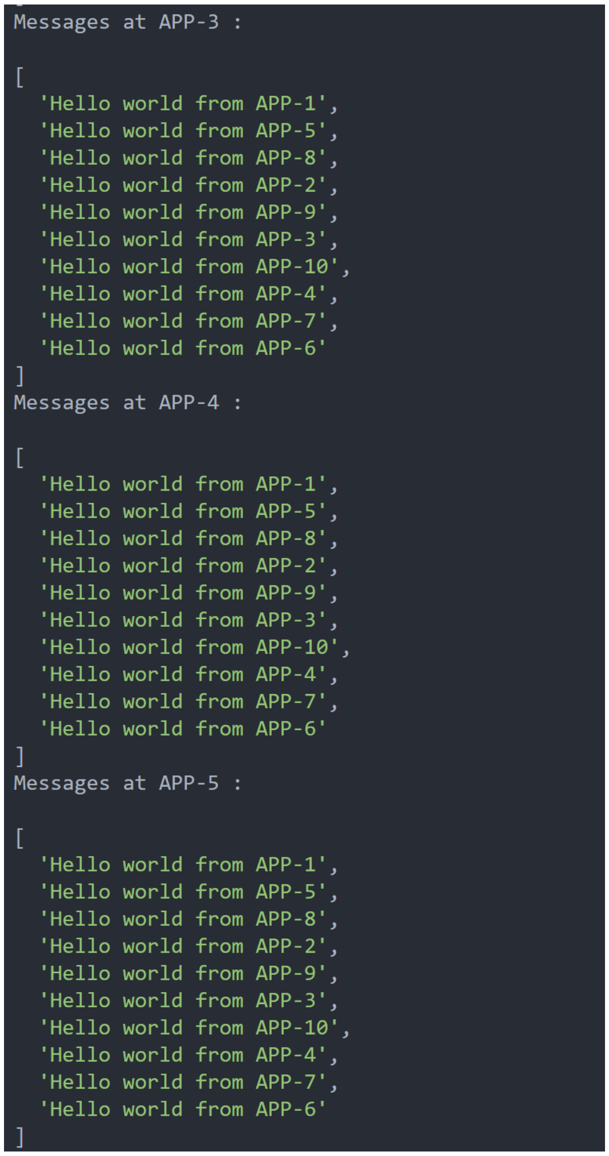
Test with 10 Applications



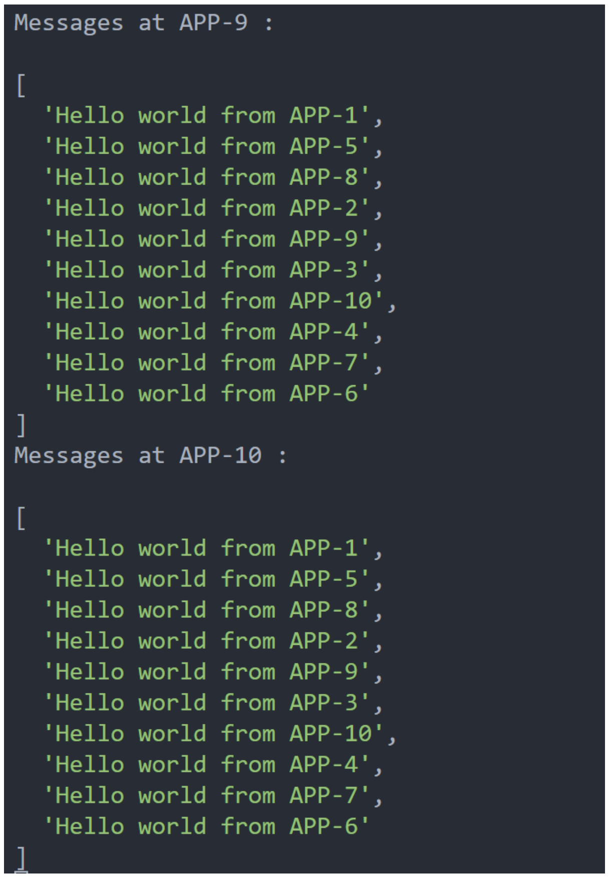
```
Status will be printed after 10 seconds....

App-8ASyeJP0-Xwj8c32AAAK Connected to Middleware
App-EorA9e0id6MvKydLAAAL Connected to Middleware
App-h6zLyidSoZznyQYlAAAM Connected to Middleware
App-hN07CM3pobgAS1_UAAAN Connected to Middleware
App-aCuQCJC1grUrrJK-AAAO Connected to Middleware
App-Su3iBDEwjeJSAaSrAAAP Connected to Middleware
App-OaRtOHvxcn5xh-b3AAAQ Connected to Middleware
App-aGxXhcv2-wzRsnigAAAR Connected to Middleware
App-eZ2ePx7wI0eS6ZnCAAAS Connected to Middleware
App-hBS5FBRso50aVZesAAAT Connected to Middleware
Messages at APP-1 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
```



```
Messages at APP-2 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
```



```
Messages at APP-3 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
Messages at APP-4 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
Messages at APP-5 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
```



```
Messages at APP-9 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
Messages at APP-10 :

[
  'Hello world from APP-1',
  'Hello world from APP-5',
  'Hello world from APP-8',
  'Hello world from APP-2',
  'Hello world from APP-9',
  'Hello world from APP-3',
  'Hello world from APP-10',
  'Hello world from APP-4',
  'Hello world from APP-7',
  'Hello world from APP-6'
]
```