RxJS: How to make an ordered mergeMap operator

An operator for when both concurrency control and ordering are important

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7 mins

An example is available on GistRun

The problem to solve

In one of my projects, I needed to assemble a PDF document where **different pages came from different sources and the result document had to contain all of them in order**. I used the pdf-lib for everything related to documents. With this library, I can create a new document, copy pages from another one then save the result as a buffer with some simple commands:

```
// create a document
const pdfDoc = await PDFDocument.create();

// source document
const pdf = // ...

// copy pages from pdf to pdfDoc
(await pdfDoc.copyPages(pdf, pdf.getPageIndices())).forEach((page) => pdfDoc.addPage(page));

// save the result document
await pdfDoc.save();
```

I had an **async function** that generated part of the result based on a config object. By calling this function with the different configs, I can generate the fragments, then use the `copyPages` + `addPage` to combine them:

```
const generatePages = async (pageConfig) => {
  // generate and return a PDF
  const pdf = ...;

  return await PDFDocument.load(pdf);
}

const pdfDoc = await PDFDocument.create();

// generate multiple pages
const pdf1 = await generatePages(pageConfig1);
const pdf2 = await generatePages(pageConfig2);
// ...

// copy all of the to pdfDoc
(await pdfDoc.copyPages(pdf1, pdf1.getPageIndices())).forEach((page) => pdfDoc.addPage(page));
(await pdfDoc.copyPages(pdf2, pdf2.getPageIndices())).forEach((page) => pdfDoc.addPage(page));
// ...

await pdfDoc.save();
```

The problem was that the `generatePages` ran slow and I wanted to parallelize it. The obvious solution is to use a `Promise.all` with an async `map` and run all the `generatePages` concurrently.

```
const pageConfigs = [...];

// generate all the input pages
const pdfs = await Promise.all(pageConfig.map(generatePages))

// build the result
const result = await pdfs.reduce(async (pdfDocProm, pdf) => {
  const pdfDoc = await pdfDocProm;
  (await pdfDoc.copyPages(pdf, pdf.getPageIndices())).forEach((page) => pdfDoc.addPage(page));
  return pdfDoc;
}, PDFDocument.create());

await result.save();
```

The above solution also takes advantage of an async `reduce` to build the result page in a serialized way.

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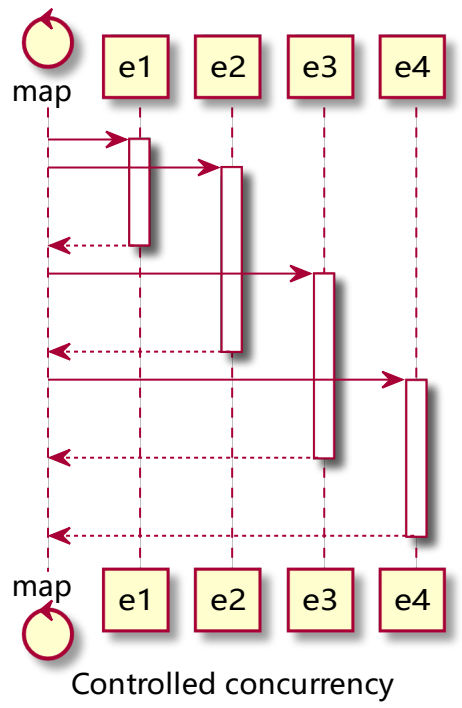
There are two problems with this solution. First, **it runs all `generatePages` in parallel**. I used Puppeteer to generate the PDF from HTML and that is memory-heavy. In practice, I could run 3-5 at a time, any more would use up all the available memory and the whole process would be a lot slower due to swapping.

The second problem is that **it generates all the input PDFs before it starts to assembly the result document.** This added more memory pressure, so I was looking for a solution that has a controllable amount of concurrency and produces elements when they become ready and in order.

RxJS `mergeMap`

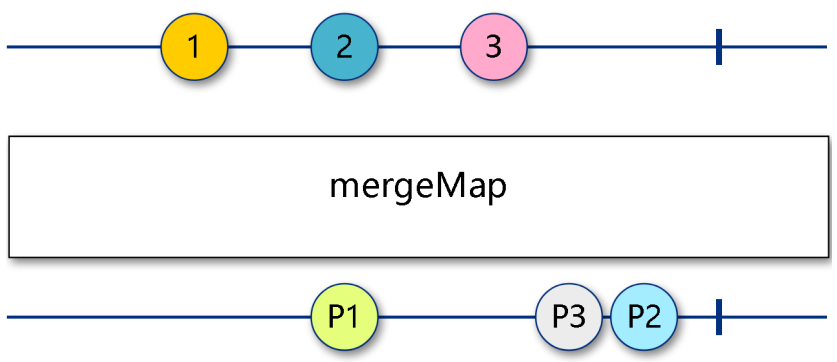
The `mergeMap`, also known as `flatMap`, is a natural choice that came into my mind for this. It **supports Promises and thus async functions nicely**, and it has **a third parameter that sets the number of parallel calls**. Whenever a task is finished, it starts a new one immediately, but never more than the concurrency cap.



This yields a nice structure:

```
// whops: not ordered

const result = await rxjs.from(pageConfigs).pipe(
  // generate pages, 3 at a time
  rxjs.operators.mergeMap(generatePages, 3),

  // build the result document as inputs become available
  rxjs.operators.reduce(async (pdfDocProm, pdf) => {
    const pdfDoc = await pdfDocProm;
    (await pdfDoc.copyPages(pdf, pdf.getPageIndices())).forEach((page) => pdfDoc.addPage(page));
    return pdfDoc;
  }, PDFDocument.create()),
).toPromise();
```

The above solution ticks the managed concurrency checkbox as well as it builds the result document when the inputs become available. But unfortunately, `mergeMap` emits elements *as they are ready* and **does not keep the original ordering of elements**.



This results in a document that has its pages out-of-order, which is wrong.

Another RxJS operator, `concatMap` preserves the ordering, but it has no support for setting the amount of concurrency. It seems like there is no built-in operator to support this use-case.

Fortunately, it's not hard to use existing operators to create new ones. The operator below is an `orderedMergeMap` that emits the elements in-order and also supports setting the concurrency.

orderedMergeMap

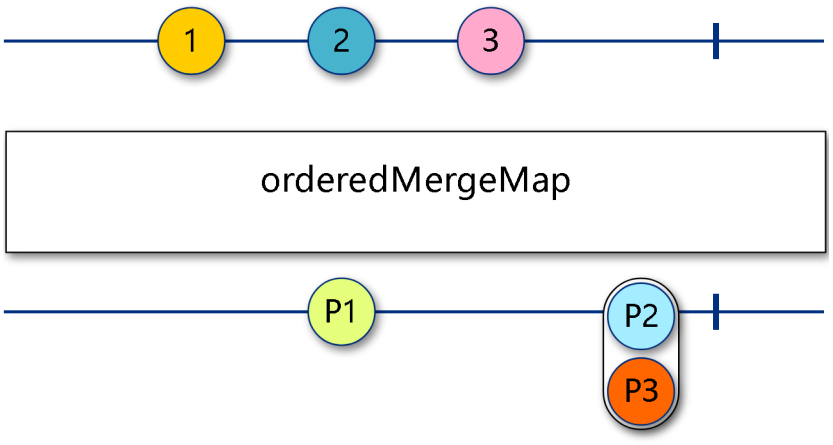
Here's the implementation that gets a Promise-producing mapper (an async function, usually) with a concurrency setting:

```
const orderedMergeMap = (mapper, concurrency) => rxjs.pipe(
  rxjs.operators.mergeMap(async (input, index) => [await mapper(input), index], concurrency),
  rxjs.operators.scan(({lastEmittedIndex, results}, [result, idx]) => {
    const emit = [...results, {result, index: idx}].map((result, _, list) => [
      result,
      [...Array(result.index - lastEmittedIndex - 1).keys()].map((i) => i + lastEmittedIndex + 1)
        .every((i) => list.find(({index}) => index === i) !== undefined)
    ]);

    return {
      emitting: emit
        .filter(([result, emit]) => emit)
        .map(([result]) => result)
        .sort((a, b) => a.index - b.index)
        .map(({result}) => result),
      lastEmittedIndex: Math.max(
        lastEmittedIndex,
        ...emit.filter(([result, emit]) => emit).map(([{index}]) => index)
      ),
      results: emit
        .filter(([result, emit]) => !emit)
        .map(([result]) => result),
    };
  }, {emitting: [], lastEmittedIndex: -1, results: []}),
  rxjs.operators.flatMap(({emitting}) => emitting)
)
```

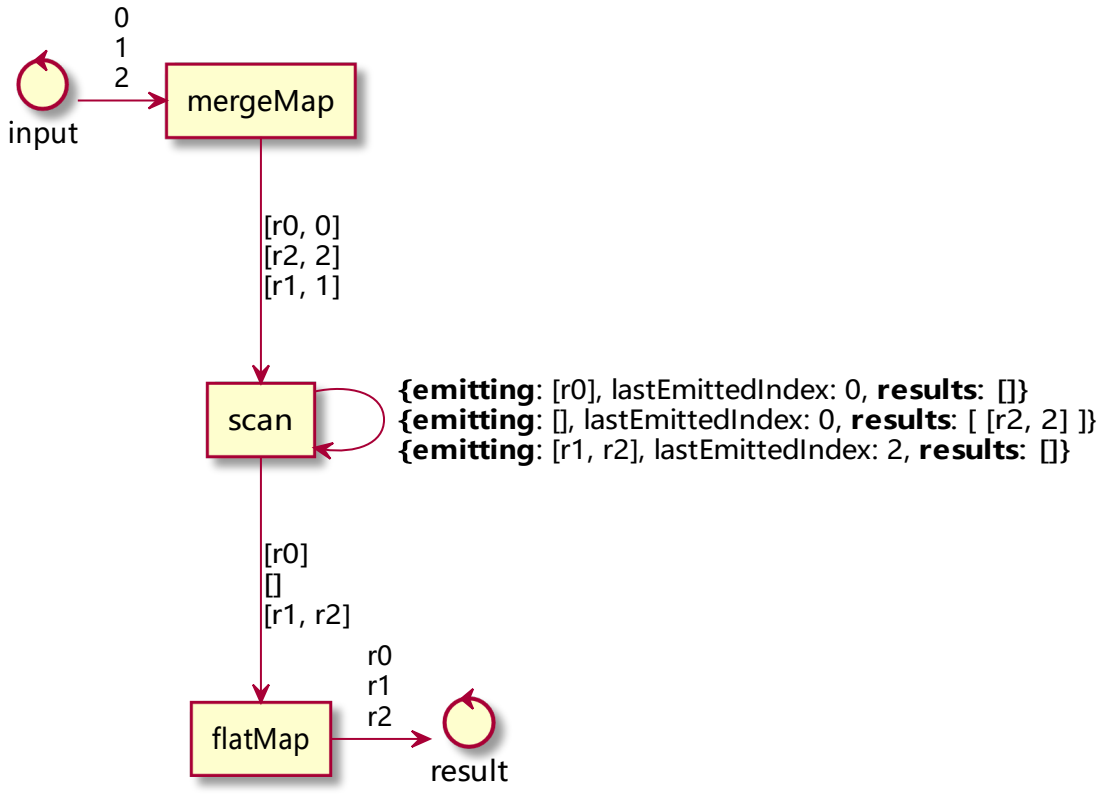
Since it's a pipeable operator, use it like any built-in one, passing the function and parallelization setting:

```
const result = await rxjs.from(pageConfigs).pipe(
  // generate pages, 3 at a time
  orderedMergeMap(generatePages, 3),

  // build the result document as inputs become available
  rxjs.operators.reduce(async (pdfDocProm, pdf) => {
    const pdfDoc = await pdfDocProm;
    (await pdfDoc.copyPages(pdf, pdf.getPageIndices())).forEach((page) => pdfDoc.addPage(page));
    return pdfDoc;
  }, PDFDocument.create()),
).toPromise();
```

In the above example, it feeds the `reduce` operator with the results in-order, no matter how long it takes for the `generatePages` to provide them.



How it works

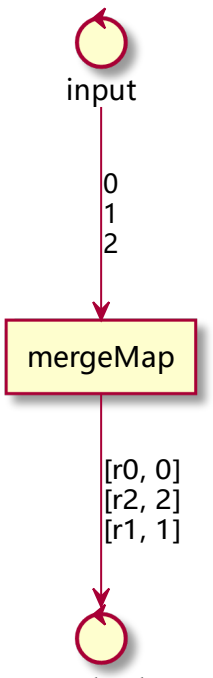


orderedMergeMap

Internally, it uses 3 operators.

```
rxjs.operators.mergeMap(async (input, index) => [await mapper(input), index], concurrency),
```

First, a `mergeMap` calls the mapper function and it controls the concurrency. It also adds the `index` to the result, so that later operators know the original ordering of the elements.

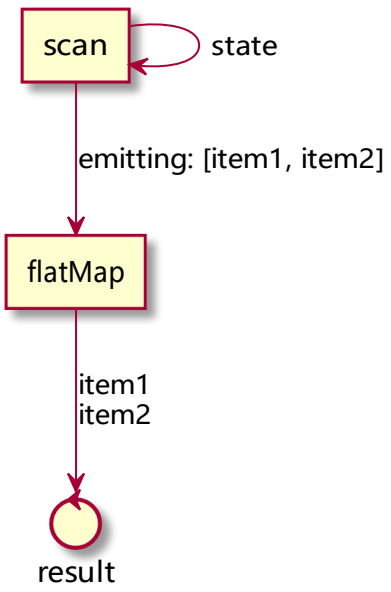


The mergeMap produces the result and adds the original index

Then a `scan` with a `flatMap` (=`mergeMap`) structure that allows storing intermediate values as the result of the `scan` and also emitting multiple items.

```
rxjs.operators.scan(({state}, item) => {
  // use stat

  return {
    emitting: [], // flatMap will emit these elements
    state: ..., // state for the next element
  }
}, {emitting: [], state: undefined}, 3),
  rxjs.operators.flatMap(({emitting}) => emitting)
```

This is a useful structure in many situations where you don’t want to use local variables. The result of the previous `scan` is fed back to the next invocation, and anything that it returns in the `emitting` array will be extracted and emitted by the `flatMap`.



A scan combined with a flatMap provides internal state

This structure moves all interesting logic inside the `scan` operator. It needs to keep track of the last element it emitted (the `lastEmittedIndex`) and all the results that are out-of-order (`results`). The latter is a buffer for elements that need to wait for a previous result before they can be emitted.

```
rxjs.operators.scan(({lastEmittedIndex, results}, [result, idx]) => {
  // mark elements as in-order or out-of-order
  const emit = [...results, {result, index: idx}].map((result, _, list) => [
    result,
    [...Array(result.index - lastEmittedIndex - 1).keys()].map((i) => i + lastEmittedIndex + 1)
      .every((i) => list.find(({index}) => index === i) !== undefined)
  ]);

  return {
    // emit in-order elements sorted by their index
    emitting: emit
      .filter(([result, emit]) => emit)
      .map(([result]) => result).sort((a, b) => a.index - b.index)
      .map(({result}) => result),
    // move the last index
    lastEmittedIndex: Math.max(
      lastEmittedIndex,
      ...emit.filter(([result, emit]) => emit).map(([{index}]) => index)
    ),
    // the buffer of out-of-order elements
    results: emit
      .filter(([result, emit]) => !emit)
      .map(([result]) => result),
  };
}, {emitting: [], lastEmittedIndex: -1, results: []}),
```

The implementation seems complicated, but it boils down to the `emit` array. It contains all results with a flag whether they can be emitted (all previous items are emitted) or not (waiting for a previous result). Then the `emitting` array in the result is the elements sorted by their original index that can be emitted, the `lastEmittedIndex` is the internal state to keep track of which elements were passed to the `flatMap`, and the `results` is the items that are still waiting.

Conclusion

The `orderedMergeMap` operator provides a way to control the concurrency of the `mergeMap` while also preserving the ordering of the elements. The implementation above uses only standard RxJS operators.

There are other solutions for this problem too, most using a local variable to store the out-of-order elements.

Javascript [68] RxJS [4]

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