Beyond Code: An Introduction to Model-Driven Software Development (CISC 836, Fall 2021)

Assignment 3 (MDSD with RSARTE)

Due: Thursday, Nov 4

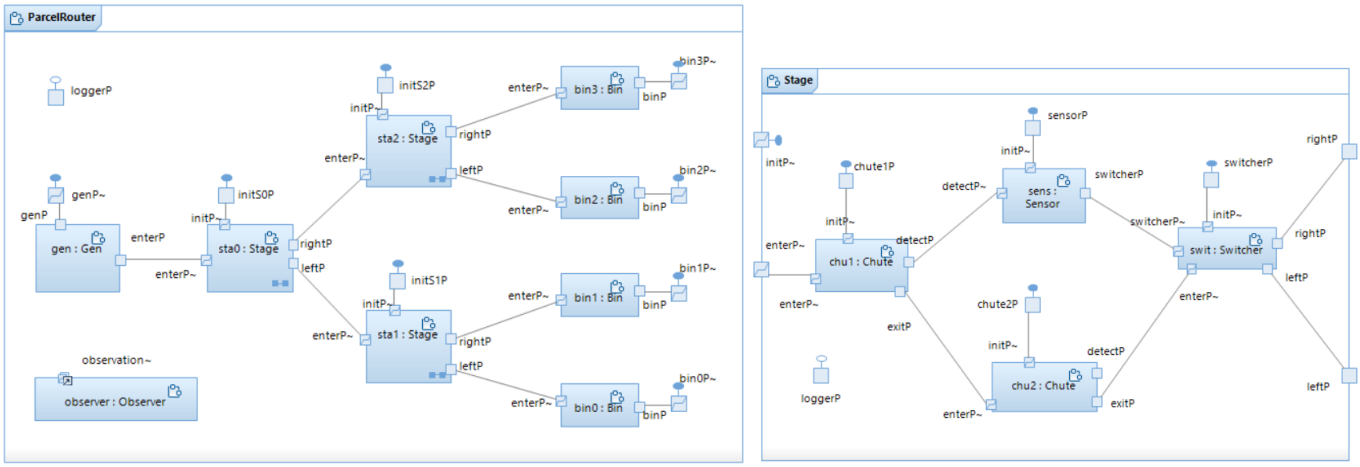
Intro

1. **Purpose of the Assignment:**
   1. Give you practical experience with timed systems and fault-tolerance (in the context of UML-RT and RSARTE) (Part I).
   2. Illustrate how UML-RT's support for dynamic instance and connector creation can be used to increase the generality of an application (Part II).
2. **Preparation:**
   1. The RSARTE installation that you used for Assignment 1 will also be used for this assignment.
   2. Make sure that you are aware of the design guidelines discussed in class.
   3. If questions come up, feel yourself encouraged to post them on the OnQ pages of the course.

Part I (40 points total)

1. **Problem Description:**
   The problem is to sort a stream of parcels (or pieces of luggage) into 'bins' according to the destination of the parcel. The central piece of hardware to be used is a 'stage' which consists of two 'chutes', one 'sensor', and one 'switcher'. A parcel will enter the stage on one end and eventually emerge on the other end from one of two openings. To form a 'parcel router', stages are arranged in a binary tree-like fashion with the opening of one stage feeding parcels directly into either the entry of the next stage or a bin. The journey of a parcel through a stage proceeds as follows:
   1. After entering the stage, the parcel will travel down the first chute ('chute1'). The time required for the parcel to go from the beginning to the end of the first chute is called 'chute1Delay'.
   2. At the end of the first chute,
      - the parcel enters the second chute ('chute2'). The time required to travel down this chute is called 'chute2Delay'.
      - the destination of the parcel is read by the sensor which uses it to determine which one of the two openings the parcel is to exit the stage from. The sensor sends this direction information (given in terms of one of two values: 0 for 'left' and 1 for 'right') to the switcher which then positions its internal routing mechanism accordingly. The operation of the sensor and the positioning of the switcher is assumed to take neglible time.
   3. At the end of the second chute, the parcel will enter the switcher and emerge at one of the ends after 'switcherDelay' seconds. Any arrival of direction information from the sensor before the parcel leaves the switcher may change the opening the parcel emerges from. In other words, the direction information from the sensor can change the direction of the parcel up until the parcel has left the switcher.
   4. At the end of the switcher, the parcel will leave the stage and either enter the next stage or reach a bin.

2. **Description of provided UML-RT model:**
   A simulation of a parcel routing system with 4 destination bins has been designed with UML-RT. The structure of this design closely mimicks that of the physical system and is shown below:



As shown in the diagrams, the router consists of nine capsule instances on the top level, while each stage contains another four instances (so, the entire router consists of no less than 22 communicating state machines, resulting in more than 7K lines of generated C++ code!):

- One instance of the generator capsule '`Gen`' that produces parcels tagged with one of four randomly generated destinations. The capsule has an internal port '`genP:GenProt`' over which it
  - receives initialization information (message '`init(args:GenInitArgs)`') from the router indicating the number of parcels to generate and the time interval with which the parcels are to be generated (class '`GenInitArgs`' wraps these parameters into a single argument),
  - lets the parcel router know which destination a recently generated parcel is to go to (message '`generated(dest:int)`'), and
  - indicates completion of the generation process (message '`done()`').
- 3 instances of the '`Stage`' capsule ('`sta0`', '`sta1`', and '`sta2`'), each with a single port '`enterP`' to receive a parcel and two ports '`leftP`' and '`rightP`' to pass on the parcel to the next stage or the destination bin. A '`Stage`' capsule instance consists of
  - 2 '`Chute`' capsule instances ('`chu1`' and '`chu2`'),
  - a '`Sensor`' capsule instance ('`sens`'), and

    - a 'Switcher' capsule instance ('swit').

  The 'Chute' and 'Switcher' capsules each contain an attribute 'delay:int' indicating how long the passage of the parcel through the unit is supposed to take. Timers are used to ensure that parcels emerge from the chutes and switchers at the prescribed time. The 'Sensor' capsule contains an attribute 'position:int' which indicates where in the parcel router the stage that the sensor is part of is located. The position of a sensor is determined by the position of the stage the sensor is in, i.e., the position of the sensor in stage sta0 is 0, the position of the sensor in stage sta1 is 1, and the position of the sensor in stage sta2 is 2. Each stage 'stai' has an internal port 'initSiP:StageInitProt' over which it receives position information for the sensor and delay information for the chutes and the switcher (message 'init(args:StateInitArgs)'). At initialization, it passes on this information to the chutes and the sensor via internal ports 'chute1P', 'chute2P', and 'sensorP', respectively.
- 4 instances of the 'Bin' capsule ('bin0', 'bin1', 'bin2', and 'bin3'). The capsule contains a port 'binP:BinProt' over which, upon arrival of a parcel, it sends the destination of that parcel to the router (message 'arrived(dest:int)').
- One instance of the 'Observer' capsule which connects the model with an animation. Over the 'observation' port, the observer receives events (message 'event(data:Event)') from the router and passes them on to the animation via a socket connection. The animation then uses them to to update the view.

For checking purposes, the parcel router contains 3 attributes in which it counts the number of parcels generated for each destination ('generated:int[4]'), the number of parcels that arrived correctly at their destination ('arrived:int[4]'), and the number of parcels that got routed to the wrong bin ('erroneousArrivals').

The state machine of the parcel router

1. collects command line arguments (if any),
2. sends intialization messages to the generator and the stages,
3. waits for 'generated(dest)' messages from the generator and increments the appropriate counter,
4. waits for 'arrived(dest)' messages from the bins, checks for incorrect routing, and then increments the appropriate counter,
5. waits for the 'done' message from the generator, and then logs the total numbers of generated and arrived parcels before it terminates.

3. **How to invoke the simulation:**
   The execution can be customized via 5 command line arguments

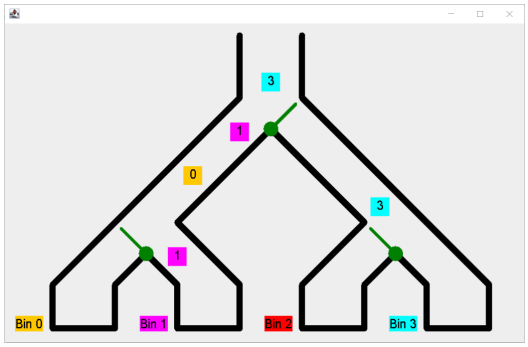
```
>> ./Parcelrouter.exe -UARGS <numParcels> <genDelay> <chute1Delay> <chute2Delay> <switchDelay>
```

   determining, respectively,

   - the total number of parcels to be generated,
   - the time interval between two successively generated parcels,
   - the amount of time the parcel needs to travel down the first chute in a stage,
   - the amount of time the parcel needs to travel down the second chute in a stage, and
   - the amount of time the parcel needs to travel down the switcher in a stage.

   If only one command line argument is used (>> ./Parcelrouter.exe -UARGS <numParcels>), it is interpreted as the number of parcels and default values are used for the delays (<genDelay>=2, <chute1Delay>=1, <chute2Delay>=1, and <switchDelay>=0). If no argument is provided, the same delay defaults are used and <numParcels> is set to 10. If a different number of arguments is given (2, 3, 4, or more than 5), execution stops with an error message. As in the previous assignments, use the command line option -URTS_DEBUG=quit to bypass the RSARTE command line debugger.

4. **How to invoke the animation:**
   The project contains a Java program that will animate executions of the simulator with the help of a socket connection over which the model sends messages whenever the animation view needs to be updated.



   To use the animation, it must be invoked first by right-clicking the 'ParcelRouterAnimation' Java project in the Project Explorer, selecting 'Run As' and then 'Java Application'. Note that:

   - When the simulation code has terminated, you also need to terminate the animation (in the 'Console' tab of RSARTE), i.e., the animation cannot be reset.
   - Once parcels traverse through the units of the router with a certain speed, the output of the animation loses its faithfulness and utility, because the amount of time that parcels will be displayed in a certain position may be too short for the parcel to be visible. For instance, the animation is useless if all delays are set to 0.
   - The simulation code can be run and the assignment can be completed without using the animation.

5. **Problems in the current model:**
   The provided model has two problems:
   1. Problem 1 (Lost parcels): When a parcel is generated or has reached the end of a chute or a switcher, the model currently passes on the parcel regardless of whether or not the next unit (i.e., chute, switcher, or bin) is empty and can actually hold that parcel. As a consequence, parcels appear to 'get lost' under certain delay settings. Problematic settings are those which cause a unit to receive a new parcel before the current one has been passed on. Examples are

      ```
      >> ./Parcelrouter.exe -UARGS 10 1 2 1 0
      >> ./Parcelrouter.exe -UARGS 10 0 1 0 2
      ```

      which, in my implementation, cause 5 and 9 parcels to get lost respectively. Lost parcels will manifest themselves in the execution as 'unexpected messages' preventing it from running to completion. Similarly, the animation will become inconsistent. Note that not all delay settings are problematic. E.g., using

```
>> ./Parcelrouter.exe -UARGS 10 1 0 0 0
>> ./Parcelrouter.exe -UARGS 10 2 1 1 0
>> ./Parcelrouter.exe -UARGS 10 3 0 1 1
```

no parcels get lost.

2. Problem 2 (Incorrect routing): The model currently routes all parcels to just one bin which is obviously incorrect. Both, the console output and the animation show this. E.g., the console output of the execution of

```
>> ./Parcelrouter.exe -UARGS 10 3 0 1 1
```

ends in

```
[ParcelR] total generations: 4 2 1 3
[ParcelR] total correct arrivals: 4 0 0 0, total incorrect arrivals: 6
[ParcelR] delay settings: 3 0 1 1
[ParcelR] duration: 34 sec, 143997000 nsec
[ParcelR] stop
```

While the animation output is useful for many (non-zero) delay settings, due to the limitations of the animation mentioned above, the console output is, in general, better suited to tell you if an execution exhibited one of the two problems above.

6. **Task description**
   - **Task 1** [0 points] Download the Parcel Router model (ParcelRouter_v0_f2021.zip), import it, and familiarize yourself with it by inspecting the model and running the code with different command line arguments.
   - **Task 2** [15 points] Fix Problem 2. More precisely, locate the parts of the model that need to be corrected and modify them such that parcels with destination 0 go to bin 0, parcels with destination 1 go to bin 1, etc. Check your fix by testing the code. Note that under the 'problematic' delay settings mentioned in the description of Problem 1, some parcels may still be directed to the wrong bin, even if your code to compute the direction is correct (due to, essentially, a stage becoming 'overloaded'). However, under non-problematic delay settings, all parcels should arrive at the correct bin, i.e., there should be no 'incorrect arrivals'.
   - **Task 3** [20 points] Fix Problem 1. More precisely, change the model so that no parcels get lost anymore regardless of any of the delay settings chosen. For instance, none of the invocations mentioned above should result in any parcels being lost. Choose **one** of the following two approaches:
     - Approach 1 (Low throughput, yet easy to implement): Change the model in such a way that the generator does not generate a new parcel until the generation delay has passed and it has received an indication from one of the bins that the previously generated parcel has arrived at a bin. Note that with this approach, parcels are transported entirely sequentially, meaning that the total amount of time required to transmit all parcels grows linearly as the product of the number of parcels and the *sum* of all delays. E.g., the invocation

       ```
       >> ./Parcelrouter.exe -UARGS 100 1 1 1 1
       ```

       would take slightly more than 600 seconds to complete. **Choosing this approach will limit the maximal number of points for this part to 14 (out of the 20 achievable).**

     - Approach 2 (Harder to implement, yet higher throughput): Approach 1 relies on sequential processing made possible through the introduction of additional connectors between the bins and the generator. Fix the problem in a way that allows higher throughput. You are not allowed to introduce new connectors, but you may, if you want, add new messages to protocols, attributes transitions, etc. Ideally, the total amount of time required drops to the product of the number of parcels and the *maximum* of the delays. E.g., in my implementation

       ```
       >> ./Parcelrouter.exe -UARGS 100 1 1 1 1
       ```

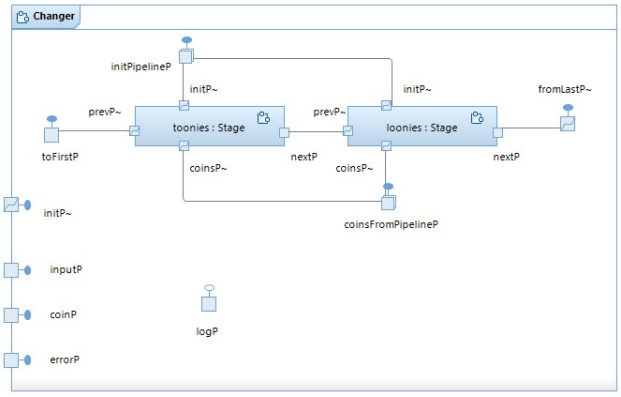
       finishes after 107 seconds.

   - **Task 4** [5 points] In a text file called 'ReadMe.txt' (which, as for the previous two assignments, is part of your project) briefly describe how the approach that you have chosen in Part 3 works, which parts of the model you have changed and how.

Part II (5 points total)

1. **Problem Description:**
   We now briefly return to the problem of giving change discussed earlier. We observe the following about all three designs in Part II of Assignment 2:
   - Coins are dispensed in order of *decreasing denominations* (i.e., first all toonies, then all loonies).
   - The amount to give loonies for is given by what is left over once the maximal number of toonies has been dispensed.
   - Ignoring the denominations, the process of giving change is *the same for toonies and for loonies* (check that the amount to give change for is greater or equal than the coin denomination d; if yes, dispense a coin, subtract d from the amount to give change for, and repeat; if not, terminate).

   These observations motivate the next design of the changer capsule:



In this design, each of the two coin denominations has its own capsule instance (called '`toonies`' and '`loonies`'). These instances are connected to form the stages of a *pipeline* in which:

- a stage receives the amount that change (still) needs to be given for from the previous stage (via port '`prevP`'; then, it gives as much change as it can (using port '`coinsP`', and passes on the remaining amount to the next stage (via '`nextP`'),
- the first and last stage connect the pipeline to the '`Changer`' capsule such that
  - the first stage receives the initial amount to give change for from '`Changer`', and
  - the last stage sends remaining amount to '`Changer`', and
- each stage is an instance of the same capsule (called '`Stage`'), and thus executes the same state machine. The changer capsule lets each stage know which denomination it is responsible for via an initialization message (sent via port '`initPipelineP`'). The '`Changer`' capsule also checks if the amount returned from the pipeline at the end of the change process is equal to 0.

This design now shows us how to come up with a *fully general solution*, i.e., a version of the changer that is parametric in the number of coins that are used for giving change and their respective denominations. For example, we want the invocation

```
$ ./executable.exe -URTS_DEBUG=quit -UARGS  81 400 200 100 10 1
```

to dispense one 200-cent coin, one 100-cent coin, one 10-cent coin, and nine 1-cent coins. That is, on the command line, the value of the selected item and the amount of money inserted is followed by a monotonically decreasing list of integers indicating the denominations of the coins to use (the number of coins is given by the length of this list):

```
$ ./executable.exe -URTS_DEBUG=quit -UARGS  <ins> <sel> <denomination of highest value coin> ... <denomination of lowest value coin>
```

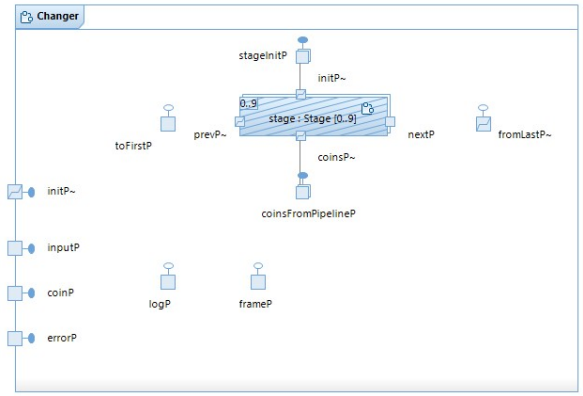
For this to be possible, the pipeline needs to be built *dynamically* (i.e., at runtime) according to the command line arguments provided. E.g., in the invocation above

- the '`Stage`' capsule needs to be instantiated four times,
- these four instances need to be connected to form a pipeline inside the changer instance,
- the stage instances need to be customized so that they give 200-cent coins, 100-cent coins, 10-cent coins, and 1-cent coins respectively.

The last design (`GiveChangeV5`) implements this using the following UML-RT features:

- *optional capsule instances* (which can be created and destroyed at runtime), and
- *unwired ports* that are wired at runtime by the application using *service access (SAPs)* and *provision points (SPPs)*.

Also, instead of sending the denomination to each stage via an initialization message, this information is provided by the changer to the instance as an argument to the '`incarnate`' function. Note how the capsule diagram of the `Changer` capsule does not show the pipeline (because it is built at runtime), but does show that the stage instances are optional and that their pipeline ports '`prevP`' and `nextP`' are unwired at the start (and, thus, wired dynamically).



2. **Task description:**
   Import and build the model realizing this fully general process of giving change (GiveChangeV5_forA3.zip). Consider the system execution caused by the following invocation:

   ```
   $ ./executable.exe -URTS_DEBUG=quit -UARGS 1575 2000 200 100 10 5
   ```

   Execute and inspect the model to understand the resulting execution. Draw a sequence diagram showing all the messages exchanged between all capsule instances (i.e., '`Top`', '`harness`', '`changer`', and all pipeline stages) as a result of this invocation. Your diagram should also include calls to the '`incarnate`' function, if any. If messages or calls to '`incarnate`' carry data, please include them as well.

   Put your sequence diagram into your parcel router project from Part I and give it the name `Part2`.

What to hand in:

- Export your modified project (**in which you have either followed Approach 1 or Approach 2, not both**) into a single archive (.zip file). Instructions: 'File' -> 'Export...' -> 'General' -> 'Archive File' -> 'Next', then select the two projects, use '`[firstName]_[lastName]_A3_CISC836_F21.zip`' as name where '`[firstName]`' and '`[lastName]`' are replaced by your first and last names, respectively. Upload this archive to OnQ.

Marking:

For Tasks 2 and 3 of Part I, your changes to the model will be marked based on their correctness and completeness (with respect to the assignment instructions and the system descripion), but also using the design guidelines discussed in class. Your answer to Task 4 be marked on completeness, precision and clarity.

Last modified: Wed Oct 20 2021 14:54:58