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# Mobile applications State Management in Flutter

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# Abstract

Abstract

**Keywords:** here, the keywords, of your thesis



# Abstract in lingua italiana

Qui va l'Abstract in lingua italiana della tesi seguito dalla lista di parole chiave.

**Parole chiave:** qui, vanno, le parole chiave, della tesi



# Contents

<b>Abstract</b>	<b>i</b>
<b>Abstract in lingua italiana</b>	<b>iii</b>
<b>Contents</b>	<b>v</b>
<b>Introduction</b>	<b>1</b>
<b>1 State management solutions</b>	<b>3</b>
1.1 SetState and InheritedWidget/InheritedModel . . . . .	3
1.2 Redux . . . . .	3
1.3 BLoc . . . . .	3
1.4 MobX . . . . .	3
1.5 GetX . . . . .	3
<b>2 The Todo app</b>	<b>5</b>
2.1 General overview . . . . .	5
2.1.1 Base functionalities . . . . .	5
2.1.2 Adding new features . . . . .	6
2.1.3 Renders optimization . . . . .	7
2.2 Implementation . . . . .	8
2.2.1 Shared project structure and files . . . . .	8
2.2.2 InheritedWidget/Model and SetState implementation . . . . .	22
2.2.3 Redux implementation . . . . .	54
2.2.4 BloC implementation . . . . .	82
2.2.5 MobX implementation . . . . .	121
<b>3 The Other app</b>	<b>143</b>
<b>4 Comparisons</b>	<b>145</b>

<b>5</b>	<b>Conslusions</b>	<b>147</b>
<b>A</b>	<b>Appendix A</b>	<b>149</b>
<b>B</b>	<b>Appendix B</b>	<b>151</b>
	<b>List of Figures</b>	<b>153</b>
	<b>List of Tables</b>	<b>155</b>
	<b>List of source codes</b>	<b>157</b>
	<b>Acknowledgements</b>	<b>163</b>



# Introduction

Introduction



# 1 | State management solutions

here i will present some main concepts and functionalities of the state management solutions proposed. This chapter will be filled with the information contained in the other word file i sent you.

## 1.1. SetState and InheritedWidget/InheritedModel

...

## 1.2. Redux

...

## 1.3. BLoc

...a

## 1.4. MobX

...

## 1.5.GetX

...



## 2 | The Todo app

This chapter is devoted to the implementation of a mobile application regarding the management of a list of todos. The application is developed using the state management solutions proposed in Chapter 1. For every solution, three different development processes are taken into account. Moreover, a series of measurements ,concerning the volume of the code and the effort spent, will be collected.

### 2.1. General overview

This section explains in details the three development processes and the resulting application.

#### 2.1.1. Base functionalities

This part of the development process aims to realize a skeleton of the application and its main functionalities. The output of the process will be an application offering the possibility to visualize and partially handle a list of todos. It is composed by a single page: the `HomePage`. The `HomePage` is made of an `AppBar` and two tabs: the *todos* tab and the *stats* tab.

The *todos* tab visualizes the list of todos. It is possible to filter todos using a `DropdownButton` widget situated in the top right corner, inside the `AppBar`. The available filter values are:

- All (visualizes completed and pending todos)
- Completed (visualizes completed todo only)
- Not Completed (visualizes pending todos only)

The list of todos is visualized using a `TodoView` component widget. The elements contained in the `TodoView` component are called `TodoItems`. `TodoItem` widgets visualize the name, the description and the completion of a specific todo using two `Text` widgets and a `Checkbox` widget. It is possible to use the checkbox in order to mark a todo as completed

or to mark it as pending depending on its current state.

The *stats* tab visualizes the number of completed todos through a Text widget. In the lower part, a TabSelector widget allow to switch from tabs.

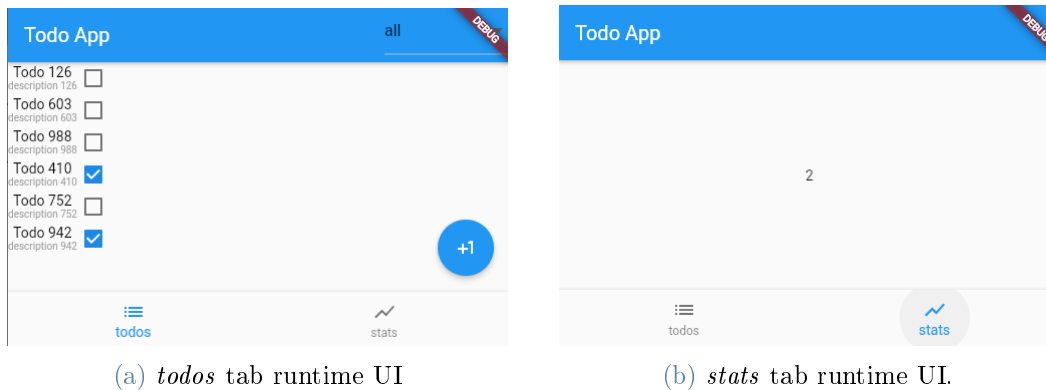


Figure 2.1: Shows the HomePage's UI

### 2.1.2. Adding new features

This part of the development process aims to add two new features to the output application of the previous step. This process is divided into two subprocesses. Both of them aims to add a single new feature.

**The Add todo Feature -** The first subprocess adds the possibility to create new todos. It utilizes the `FloatingActionButton` widget, already present in the bottom right corner of the application, to push a new page called `AddTodoPage`. In the `AddTodoPage` is possible to compile two `TextField` widgets and tap on a `TextButton` widget to return to the `HomePage` creating the new todo.

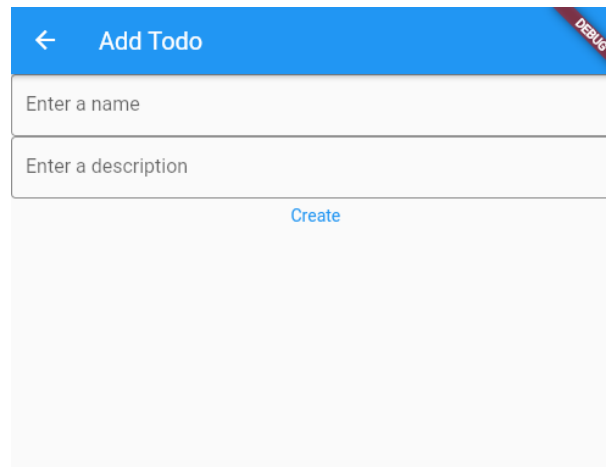


Figure 2.2: Shows the AddTodoPage's UI

**The Update feature** - The second subprocess aims to add the possibility to update existing todos. Tapping on a specific `TodoItem` widget allows to navigate to a new page called `UpdateTodoPage`. In the `UpdateTodoPage` is possible to compile two `TextFields` widgets and tap on a `TextButton` widget to return to the `HomePage` modifying the corresponding todo.

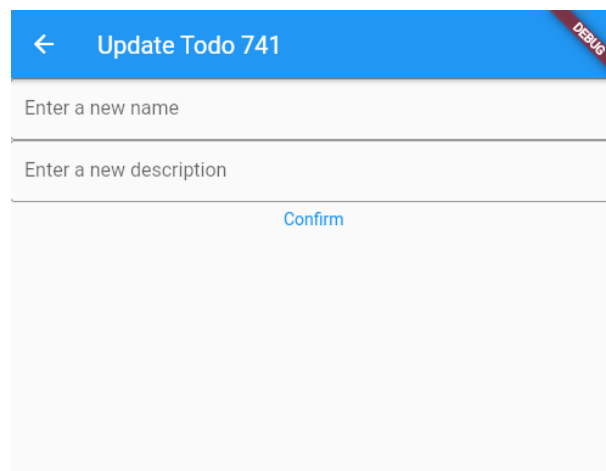


Figure 2.3: Shows the UpdateTodoPage's UI for the todo with id 741

### 2.1.3. Renders optimization

This part of the development process aims to perform some optimizations in terms of UI renderings and memory consumption. In particular, the code will be refactored in order to use the least UI renders possible or, in other words, to call the least *build* method's runs possible. The focus is on the `TodoView` widget and `TodoItem` widgets. The `TodoView`

widget should be rendered again only after a structural change in the *filteredTodos* list. The *filteredTodos* list represent the list containing the todos matching the current filter. A structural change is intended as a mutation of the length of the list or a substitution of its internal elements. Basically, a structural change occurs when a new todo is added or removed from the list and/or when the filter changes. If the *filteredTodos* list's change concerns a single todo (e.g. when its internal state is changed using the checkbox or the update feature) it is considered a non-structural change. The main difference is that, a structural change, needs to rebuild the entire *TodoView* widget ,instead , a non-structural change can rebuild only a subpart (the particular *TodoItem* widget). When a structural change occurs, more than one *TodoItem* widget is affected by the change. The most convinient way to mutate all the *TodoItem* widgets consistently is to rebuild the entire *TodoView* widget. Moreover, adding , deleting and substituting a *TodoItem* (and consequently add/delete/substitute a child to the *TodoView* tree's node) is only feasible by the parent widget and not by widgets on the same tree level. A non-structural change ,instead, affects only a specific *TodoItem*/child and so, it is possibile to rebuild the single element only. Those optimizations are not really necessary in this scenario. The implemented application is ,indeed, very simple and do not need this kind of improvements at all. This is just an experiment in order to define which solution performs better at handling optimizations and to give an adjunctive prospective in the final comparison.

## 2.2. Implementation

This section contains the implementation of the application presented in Section 2.1 using the state management solutions proposend in Chapter RIFERIMENTO.

### 2.2.1. Shared project structure and files

In order to make comparisons even fairer , the code about the application's core and about the UI is shared between different solution. In this way , measurements are taken considering only the parts of the code added by each solution's implementation. This subsection presents the shared parts in details. Some parts of the code can change from one implementation to another in order to adapt to the solution's pattern. However, changes to the structure are kept minimal and the same is for the UI. It uses the least widgets and visual elements possible. In Figure 2.4 the shared folder's and file's structure is shown. Subsequent paragraphs exaplain how models, pages, components and the repository are implemented.



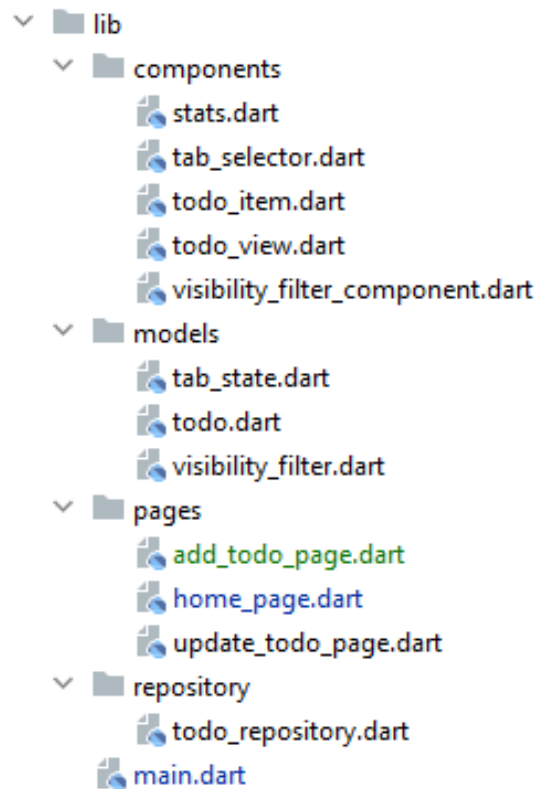


Figure 2.4: Shows Todos app's shared files structure

**The application's Root** - The root widget of the application is called MyApp. It is a stateless widget composed by a MaterialApp widget. Inside the MaterialApp widget, three routes are defined : the HomePage , the UpdateTodoPage and the AddTodoPage. The *inicialRoute* is set to the HomePage as deaful. The UpdateTodoPage takes a Todo instance as argument. Inside the *main* function the MyApp widget is passed to the *runApp* method in order to start the application.

**Source Code 2.1:** Todo app - MaterialApp and main function implementation

```
void main() {  
  //launching the application  
  runApp(const MyApp());  
}  
  
class MyApp extends StatelessWidget {  
  const MyApp({Key? key}) : super(key: key);  
  
  @override
```

```
Widget build(BuildContext context) {
  return MaterialApp(
    initialRoute: "/", //setting initial route to the HomePage
    routes: { //defining possible routes
      "/": (context) => const HomePage(),
      "/updateTodo": (context) => UpdateTodoPage(
        todo: (ModalRoute.of(context)!.settings.arguments
          as Todo),
      "/addTodo": (context) => AddTodoPage(),
    },
  );
}
```

**Models** - The model for the HomePage's tabs is implemented using an enumeration.

**Source Code 2.2:** Todo app - TabState model implementation

```
enum TabState{
  todos,stats
}
```

Filters for the *filteredTodos* list are modelled by an enumeration too. They can take three values: *all*, *notCompleted*, *completed*.

**Source Code 2.3:** Todo app - VisibilityFilter model implementation

```
enum VisibilityFilter{
  completed,notCompleted,all
}
```

It's not possible to give a common implementation for the Todo model matching every solution. Todo model, indeed, can change in different implementations. The sharable structure of the model, however, can be defined as shown in Source Code 2.4

**Source Code 2.4:** Todo app - Todo model implementation

```
@immutable
class Todo {
  final int id;
  final String name;
  final String description;
  final bool completed;

  const Todo(
    {required this.id,
    required this.name,
    required this.description,
    required this.completed});

  @override
  bool operator ==(Object other) {
    return (other is Todo) &&
      other.description == description &&
      other.name == name &&
      other.id == id &&
      other.completed == completed;
  }

  @override
  String toString() {
    return "{ id: $id completed: $completed}";
  }

  @override
  // TODO: implement hashCode
  int get hashCode => super.hashCode;
}
```

**Repository and utilities** - Some useful functions are shared between different implementations. They are contained in the `utility.dart` file. *generateId* function takes a list of todos and generate a new unique id. *todoExists* function takes a list of todos and a id and checks if a todo with that id exists.

**Source Code 2.5:** Todo app - Utility functions implementation

```
int generateId(List<Todo> todos) {
    Random rand = Random();
    int newInt = rand.nextInt(1000) + 2;
    List<int> ids = todos.map((todo) => todo.id).toList();
    while (ids.contains(newInt)) {
        newInt = rand.nextInt(1000) + 2;
    }
    return newInt;
}

bool todoExists(List<Todo> todos, int id) {
    List<Todo> result = todos.where((todo) => todo.id == id).toList();
    return result.isNotEmpty ? true : false;
}
```

The `TodoRepository` class simulates the todos's fetching process from a Database. It has two static methods. These methods are asynchronous and have a duration of 2 seconds to give the impression of a real asynchronous operation. The method *loadTodos*, in particular, populates a list with six new todo instances, using the *generateId* function for the generation of their unique IDs. Subsequently, 2 seconds later, it returns the list to the caller.

**Source Code 2.6:** Todo app - `TodoRepository` implementation

```
class TodoRepository {
    //generate 6 unique todos
    static Future<List<Todo>> loadTodos() async {
        List<Todo> todos = [];
        Random rand = Random();
        while (todos.length < 6) {
            int newInt = generateId(todos);
            todos.add(Todo(
                id: newInt,
                name: "Todo " + newInt.toString(),
```

```

        description: "description " + newInt.toString(),
        completed: rand.nextBool()));
    }
    //waiting 2 seconds before returning the list
    await Future.delayed(const Duration(seconds: 2));
    return todos;
  }

  static Future<void> saveTodos(List<Todo> todos) async {
    await Future.delayed(const Duration(seconds: 2));
  }
}

```

**Components** - Components are widgets created with a specific task. They provide some sort of independent functionality. `TodoView` widget component, for example, takes care of visualizing a list of todos. Todos are accessed in different ways depending on the implementation. `TodoView` widget uses a `ListView` widget filled with `TodoItem` widgets. `itemCount` and `itemBuilder` fields are left empty for future implementation.

**Source Code 2.7:** Todo app - `TodoView` component implementation

```

class TodoView extends StatelessWidget {

  const TodoView({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building TodoView");

    return ListView.builder(
      itemCount: //to be filled,
      itemBuilder: (context, index) {
        return TodoItem(
          todo: //to be filled
        );
      },
    ),
  }
}

```

```

    );
  }
}

```

TodoItem widget component takes care of visualizing a specific todo. TodoItem widget is a stateless. It uses two Text widgets in order to display the todo's informations and a Checkbox widget to allow changing the todo's *completed* field. The entire TodoItem widget is wrapped into an InkWell widget to make it responsive to taps. Functions fields are left empty for future implementation.

### Source Code 2.8: Todo app - TodoItem component implementation

```

class TodoItem extends StatelessWidget {
  final Todo todo;

  const TodoItem({Key? key, required this.id}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Todo Item \${todo}");

    return InkWell(
      onTap: () {
        Navigator.pushNamed(context, "/updateTodo" , arguments: todo);
      },
      child: Row(
        children: [
          Column(
            children: [
              Text(todo.name,
                style: const TextStyle(fontSize: 14,
                  color: Colors.black)),
              Text(todo.description,
                style: const TextStyle(fontSize: 10,
                  color: Colors.grey)),
            ],
          ),
        ],
      ),
    );
  }
}

```

```

        ],
      ),
      Checkbox(
        value: todo.completed,
        onChanged: (value) {
          //to be filled
        },
      ),
    ],
  ),
);
}
}

```

TabSelector component allows to switch from tabs. It uses a BottomNavigationBar widget. Its *items* field is populated with a list of BottomNavigationBarItem widgets that comes from the mapping of all possible TabState values to BottomNavigationBarItem widgets. Function fields are left empty for future implementation. Functions fields are left empty for future implementation.

#### Source Code 2.9: Todo app - TabSelector component implementation

```

class TabSelector extends StatelessWidget {

  const TabSelector(
    {Key? key})
    : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Tab Selector");

    return BottomNavigationBar(
      currentIndex: //to be filled ,
      onTap: (){
        //to be filled
      },
    ),
  },
}

```

```

        items: TabState.values
        .map((tab) => BottomNavigationBarItem(
            label: describeEnum(tab),
            icon: Icon(
                tab == TabState.todos ? Icons.list : Icons.show_chart,
            ),
        ))
        .toList(),
    );
}
}

```

VisibilityFilterSelector component uses a `DropDownButton` widget. Its *items* field is populated with a list of `DropDownMenuItem` widgets that comes from the mapping of all possible `VisibilityFilter` values to `DropDownMenuItem` widgets. Function fields are left empty for future implementation.

**Source Code 2.10:** Todo app - VisibilityFilterSelector component implementation

```

class VisibilityFilterComponent extends StatelessWidget {

  const VisibilityFilterComponent(
    {Key? key})
    : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Visibility filter");

    return DropDownButton<VisibilityFilter>(
      value: //to be filled,
      items: VisibilityFilter.values.map((filter) {
        return DropDownMenuItem<VisibilityFilter>(
          child: Text(describeEnum(filter)), value: filter);
      }).toList(),
      onChanged: (filter) {

```



```
        //to be filled
    },
);
}
```

Stats component takes care of visualizing some numerical representation regarding the list of todos. Stats component is a stateless widget composed by a Text widget, showing the stats value, wrapped into a Center widget.

**Source Code 2.11:** Todo app - Stats component implementation

```
class Stats extends StatelessWidget {
  const Stats({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Stats");

    return Center(
      child: Text(
        // to be filled
      ));
  }
}
```

**Pages** - The HomePage can be a statefull widget or a stateless widget depending on the utilized solution. In both cases it uses a simple Scaffold widget. The AppBar widget contains a VisibilityFilterSelector component only when the tab is set to *todos*. The *body* is filled with a TodoView component if the tab is set to *todos* and with a Stats component if the tab is set to *stats*. The *body* can change from *todos* tab to *stats* tab using the BottomNaviagationBar (filled with the TabSelector widget). An empty FloatingActionButton widget is also present for future implementation. (note: some small pieces could change in different solution's implementation. In the above example the tab value is contained in the HomePage but it will not be always the case).

Source Code 2.12: Todo app - HomePage implementation

```
class HomePage extends StatefulWidget {
  const HomePage({Key? key}) : super(key: key);

  @override
  State<HomePage> createState() => _HomePageState();
}

class _HomePageState extends State<HomePage> {
  TabState tab = TabState.todos; //example of tab handling

  @override
  Widget build(BuildContext context) {
    return Scaffold(
      appBar: AppBar(
        actions: [
          tab == TabState.todos
            ? const VisibilityFilterComponent()
              : Container()
        ],
        title: const Text("Todo App"),
      ),
      body: tab == TabState.todos ? const TodoView() : const Stats(),
      bottomNavigationBar: TabSelector(),
      floatingActionButton: tab == TabState.todos
        ? FloatingActionButton(
            child: const Icon(Icons.plus_one),
            onPressed: () {
              Navigator.pushNamed(context, "/addTodo");
            },
          ) : Container(),
    );
  }
}
```

```
}
```

The `UpdateTodoPage` is statefull and uses a `Scaffold` widget too. The reason why it is implemented with a statefull widget is that it uses `TextEditingController` objects which need a statefull widget to work properly. The *body* is filled with a `Column` widget containing two `TextField` widgets and a `TextButton` widget. The `TextButton` widget *onPressed* field is left empty for future implementation.

**Source Code 2.13:** Todo app - `UpdateTodoPage` implementation

```
class UpdateTodoPage extends StatefulWidget {
  final Todo todo;

  const UpdateTodoPage({Key? key, required this.todo})
    : super(key: key);

  @override
  State<UpdateTodoPage> createState() => _UpdateTodoPageState();
}

class _UpdateTodoPageState extends State<UpdateTodoPage> {
  final textControllerName = TextEditingController();
  final textControllerDesc = TextEditingController();

  @override
  Widget build(BuildContext context) {
    return Scaffold(
      appBar: AppBar(
        title: Text("Update Todo" + widget.todo.name),
      ),
      body: Column(
        children: [
          TextField(
            controller: textControllerName,
            decoration: const InputDecoration(
              border: OutlineInputBorder(),

```

```

        hintText: 'Enter a new name'),
    ),
    TextField(
        controller: textControllerDesc,
        decoration: const InputDecoration(
            border: OutlineInputBorder(),
            hintText: 'Enter a new description'),
    ),
    TextButton(
        onPressed: () {
            //to be filled
        },
        child: const Text("Confirm")),
    ],
));
}

@override
void dispose() {
    textControllerName.dispose();
    textControllerDesc.dispose();
    super.dispose();
}
}

```

The `AddTodoPage` is statefull and uses a `Scaffold` widget. The `body` field is filled with a `Column` widget containing two `TextField` widgets and a `TextButton` widget. The `TextButton` `onChanged` field is left empty for future implementation.

**Source Code 2.14:** Todo app - `AddTodoPage` implementation

```

class AddTodoPage extends StatefulWidget {
    final void Function(String, String) addTodoCallback;

    const AddTodoPage({Key? key, required this.addTodoCallback})
        : super(key: key);
}

```

```
@override
State<AddTodoPage> createState() => _AddTodoPageState();
}

class _AddTodoPageState extends State<AddTodoPage> {
  final textControllerName = TextEditingController();
  final textControllerDesc = TextEditingController();

  @override
  Widget build(BuildContext context) {
    return Scaffold(
      appBar: AppBar(
        title: const Text("Add Todo"),
      ),
      body: Column(
        children: [
          TextField(
            controller: textControllerName,
            decoration: const InputDecoration(
              border: OutlineInputBorder(), hintText: 'Enter a name'),
          ),
          TextField(
            controller: textControllerDesc,
            decoration: const InputDecoration(
              border: OutlineInputBorder(),
              hintText: 'Enter a description'),
          ),
          TextButton(
            onPressed: () {
              //to be filled
            },
            child: const Text("Create"))
        ],
      ));
  }
```

```
@override
void dispose() {
  textControllerName.dispose();
  textControllerDesc.dispose();
  super.dispose();
}
}
```

Here ends the implementation of the shared code.

### 2.2.2. InheritedWidget/Model and SetState implementation

This section implements the Todo application using two standard tools the Flutter framework provides in order to handle the state. These tools are InheritedWidgets and InheritedModels plus the usual *setState* function.

#### Base functionalities

**The core state** - In order to use InheritedWidget's functionalities, a new class must be defined and extended with InheritedWidget class. For our purpose, a single class will be enough to contain all the application's state. This new class is called *TodoInheritedData*.

**Source Code 2.15:** Todo app - InheritedWidget - extension to InheritedWidget

```
class TodoInheritedData extends InheritedWidget{
```

The application's state is composed by: a list of Todos, a VisibilityFilter , an Int for the stats ( for conciseness it will represent the number of completed todos) and a filtered list of todos which contains the todos matching the visibility filter. Inside the constructor, final variables are initialized with their corresponding arguments, moreover, *stats* and *filteredTodos* list are computed.

**Source Code 2.16:** Todo app - InheritedWidget- TodoInheritedData implementation

```
class TodoInheritedData extends InheritedWidget{
  final List<Todo> todos;
  final List<Todo> filteredTodos;
  final VisibilityFilter filter;
  final int stats;

  TodoInheritedData(
    {
      Key? key,
      required this.todos,
      required this.filter,
      required Widget child})
    : stats = todos.length, //computing stats
      filteredTodos = filterTodo(todos, filter), //computing filtered list
      super(child: child, key: key);
}
```

*filterTodos* function is just a function taking a list of todos and a visibility filter and returning the filtered list. Important to notice is the fact that a *child* widget must also be provided in the constructor. This because *TodoInheritedData* is nothing else than a widget itself that wraps the state and makes it accessible down the tree.

*TodoInheritedData* widget is stateless. It cannot be changed (every value is final) and a new *TodoInheritedData* widget must be provided when a data change occurs. The *updateShouldNotify* method must be overridden inside the *TodoInheritedData* class. This method belongs to the *InheritedWidget* class and its override is mandatory. It helps avoiding useless UI rebuilding when a new state, without actual data changes, occurs. Once a *TodoInheritedData* widget is replaced with a new one, the new widget takes care of calling the *updateShouldNotify* method and deciding whether is necessary to notify changes in the subtree. If the method returns *true* , the subtree is rebuilt, if it returns *false*, instead, it is not.

**Source Code 2.17:** Todo app - *InheritedWidget* - *TodoInheritedData*'s *updateShouldNotify* method override

```
@override
bool updateShouldNotify(TodoInheritedData oldWidget) {
  return !listEquals(oldWidget.filteredTodos, filteredTodos);
}
```

*listEquals* function is provided by the Dart language. It takes two lists and compares them element by element, returning true if all elements are equal. In the Source Code 2.17, it takes as parameters the old *filteredTodos* list (the one belonging to the old widget) and the new *filteredTodos* list and compares them. In case no changes were performed it returns *true* and leads the *updateShouldNotify* function to return *false*, leaving the subtree unchanged.

InheritedWidget class requires also the *of* method override. The *of* method makes the instance of the *TodoInheritedData* class accessible down the tree. It is a static method (it can be called without instantiating any *TodoInheritedData* object) and returns the instance of the nearest *TodoInheritedData* widget up in the tree. It extracts the instance from the current *context* object using the method called *dependOnInheritedWidgetOfExactType* provided by the Flutter framework. In case no *TodoInheritedData* widget is found it raises a runtime error.

**Source Code 2.18:** Todo app - InheritedWidget - *TodoInheritedData* *of* method override

```
static TodoInheritedData? of(BuildContext context) {
  final TodoInheritedData? result =
    context.dependOnInheritedWidgetOfExactType<TodoInheritedData>();
  assert(result != null, 'No TodoInheritedData found in context');
  return result;
}
```

*TodoInheritedData* widget is now ready to be used. In the overall it is a container for our state. It makes the state accessible in the subtree but, is not clear yet who is really filling it with the correct informations. *TodoInheritedData* widget represents the state of the application in a given moment. It cannot change its internal values neither substitute itself with another instance. In practice, what happens, is that a stateful widget is created. This stateful widget contains the state and bothers to create a new instance of the *TodoInheritedData* widget every time the state changes. Everytime its internal state is changed (using *setState*), indeed, a new instance of *TodoInheritedData* widget



is produced and substituted with the old one. In this way, changes are reported to the subtree which sees a different image of the state and rebuild with it. I personally did not appreciate this adjunctive data cache layer `InheritedWidget` introduces. On one way it is simple and works really well for its purpose , on the other hand it introduces a new level of data caching. The concept of data caching will be explained a bit more in details later but ,for the moment ,we can say that the application's state is not exactly atomic/unique. What is seen by the subtree is a screenshot of the state and not the state itself. The real state is contained in the stateful widget. It is important, though, that the real state and the screenshot provided in the subtree are well synchronized. A bad synchronization can produce inconsistency in what is visualized and the information contained in the internal state. More in general, it can be said , that the more data caching levels are introduced the harder it gets to efficiently synchronize them. It is clear that ,in our scenario ,this problem does not really show up. Or better, it will in the optimization part but ,in that case, `InheritedWidget` tool is used with a purpose that goes behind its real usage. Anyway, it is possible that different widgets sees different screenshots of the data and the bigger the application grows the higher will be the probability that this scenario show up. Now that the background is a bit clearer the implementation process can continue. As mentioned above, a new stateful widget must be created. This new stateful widget is called *TodoProvider*. It has two variables representing the state: a list of todos and a filter. (the rest of the state is computed at each `TodoInheritedData` creation)

**Source Code 2.19:** Todo app - `InheritedWidget` - `TodoProvider` widget implementation

```
class TodoProvider extends StatefulWidget {
  const TodoProvider({Key? key, required this.child}) : super(key: key);

  final Widget child;

  @override
  _TodoProviderState createState() => _TodoProviderState();
}

class _TodoProviderState extends State<TodoProvider> {
  List<Todo> todos = [];
  VisibilityFilter filter = VisibilityFilter.all;
```

```
@override
Widget build(BuildContext context) {
  return TodoInheritedData(
    todos: todos,
    filter: filter,
    child: widget.child,
  );
}
```

Note that the `VisibilityFilter` is set as *all* by default. In the statefull widget's *init* method, todos are fetched from the repository and pushed inside the *todos* variable using the *setState* method.

**Source Code 2.20:** Todo app - InheritedWidget - TodoProvider 's *init* method implementation

```
@override
void initState() {
  TodoRepository.loadTodos().then((todos) {
    setState(() {
      this.todos = todos;
    });
  });
  super.initState();
}
```

At this point, our `TodoProvider` widget can be incorporated as the parent of the `Scaffold` widget in the `HomePage`. The usage of the `Builder` widget is due to the fact that the instance of `TodoInheritedData` is only accessible in a context where a `TodoProvider` is already present. In other words, `TodoProvider`'s data cannot be accessed in the same *build* method where it was instantiated into. Two options are possible; creating a separated file where to put our `Scaffold`, or use a `Builder` widget that takes the current context and creates another one containing the `TodoProvider` widget.

**Source Code 2.21:** Todo app - InheritedWidget - Data injection in the `HomePage`'s subtree

```

class _HomePageState extends State<HomePage> {
  TabState tab = TabState.todos;

  @override
  Widget build(BuildContext context) {
    return TodoProvider(// new TodoProvider widget
      child: Builder(// new Builder widget
        builder: (context) {
          return Scaffold(...) // the rest of the HomePage;
        }
      ),
    );
  }
}

```

**The TodoView component** - TodoView component can now be populated. It is a stateless widget that looks up for the *filteredTodos* list, contained in the TodoInheritedData widget. It uses the *of* method, defined in Source Code 2.18, to access the nearest TodoInheritedData instance. Then, it uses the list to populate the ListView widget.

**Source Code 2.22:** Todo app - InheritedWidget - TodoView component implementation

```

class TodoView extends StatelessWidget {

  const TodoView({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building TodoView");
    //retrieving the filtered list from the state
    final List<Todo> filteredTodos =
      TodoInheritedData.of(context).filteredTodos;

    return ListView.builder(

```

```

    itemCount: filteredTodos.length, // to use it here
    itemBuilder: (context, index) {
      return TodoItem(
        todo: filteredTodos.elementAt(index), // and here
      );
    },
  );
}
}

```

**The VisibilityFilterSelector component** - At this point we got a single page (HomePage) that uses a `TodoView` widget to show the *filteredTodos* list contained in the `TodoInheritedData` widget. When the application starts, an empty page appears (todos are empty at the beginning) and then, after a few seconds, a list of todos, with their names, descriptions and completions, is shown. The list of filtered todos can be visualized, but is not interactable yet. In the `HomePage`'s `AppBar`, a `VisibilityFilterSelector` component is ready to be used as defined in Source Code 2.10. Its current `DropDownButton`'s *value* field is filled looking up for the *filter* value in the `TodoInheritedData` widget.

**Source Code 2.23:** Todo app - `InheritedWidget` - `VisibilityFilterSelector` component implementation

```

class VisibilityFilterComponent extends StatelessWidget {

  const VisibilityFilterComponent(
    {Key? key})
    : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Visibility filter");
    // retrieving the visibility filter from the state
    VisibilityFilter filter= TodoInheritedData.of(context).filter;
    return DropDownButton<VisibilityFilter>(
      value: filter, // use it here
    );
  }
}

```

```

        items: VisibilityFilter.values.map((filter) {
            return DropdownMenuItem<VisibilityFilter>(
                child: Text(describeEnum(filter)), value: filter);
        }).toList(),
        onChanged: (filter) {
            //to be implemented
        },
    );
}
}

```

The *onChanged* field must be populated with a function that takes as single argument a *VisibilityFilter* value. This function is called when a *DropdownMenuItem* is tapped by the user. It contains, as argument, the tapped *DropdownMenuItem*'s filter value. We want this function to change the state contained in the *TodoInheritedData* widget (the *filter* variable) when fired. In order to do so, a state changing function must be provided, by the *TodoInheritedData* widget, to be accessed and called, by widgets. As we mentioned earlier, *TodoInheritedData* widget contains only final fields and should never be modified. It is not possible, indeed, to directly change the values inside the *TodoInheritedData* widget. For this reason, just adding a new function inside the *TodoInheritedData* widget, to perform the change, is not a solution. Indeed, trying to change a part of the state, inside this ipotetic function, will generate an error at compile time (final variable cannot be set outside constructor). A completely new *TodoInheritedData* widget, indeed, should be created. The *TodoInheritedData* widget is created in the *TodoProvider* widget, when the *build* method runs, using its local variables *todos* and *filter*. In order to generate a new *TodoInheritedData* widget, is sufficient to change the *TodoProvider* widget's local state, using the *setState* method. This will cause the *build* method to run again with the new values and to generate a new *TodoInheritedData* widget. At this point should be clear that the state changing function comes from the *TodoProvider* widget. This function, once called, changes the local state of the *TodoProvider* stateful widget generating a new state for the application.

In practice, a new function, called *onChangeFilter*, is added inside the *TodoProvider* widget. This function takes a *VisibilityFilter* value as parameter and sets the value of *TodoProvider*'s *filter* variable using the *setState* method.

**Source Code 2.24:** Todo app - InheritedWidget - TodoProvider's *onChangeFilter* field implementation

```
void onChangeFilter(VisibilityFilter filter) {
    setState(() {
        this.filter = filter;
    });
}
```

Once called, being the state (the part concerning the filter) changed, another run of the *build* method is performed. As a consequence the *TodoInheritedData* widget, present in the tree, is replaced with the new one. However, widgets access the state through the *TodoInheritedData* widget and not through the *TodoProvider* widget. For this reason, an instance of the *onChangeFilter* function must be provided to the *TodoInheritedData* widget to make it accessible in the subtree. A new parameter is added, though, in the *TodoInheritedData* class.

**Source Code 2.25:** Todo app - InheritedWidget - *TodoInheritedData* widget expansion

```
class TodoInheritedData extends InheritedWidget {
    final List<Todo> todos;
    final List<Todo> filteredTodos;
    final void Function(VisibilityFilter) onChangeFilter; //new variable
    final int stats;
    final VisibilityFilter filter;
```

The *onChangeFilter* function is then passed to the *TodoInheritedData* widget on its creation.

**Source Code 2.26:** Todo app - InheritedWidget - *onChangeFilter* function injection into *TodoInheritedData* widget

```
@override
Widget build(BuildContext context) {
    return TodoInheritedData(
```

```

    todos: todos,
    onChangeFilter: onChangeFilter, //new argument
    filter: filter,
    child: widget.child,
  );
}

```

Now that the *onChangeFilter* function is accessible down in the tree, it can be called in the *onChange* field of the *DropDownButton* widget, inside the *VisibilityFilterSelector* component.

**Source Code 2.27:** Todo app - *InheritedWidget* - *DropDownButton*'s *onChanged* field implementation

```

onChanged: (filter) {
  TodoInheritedData.of(context).onChangeFilter(filter!);
},

```

It is now possible to apply different filters to the list of todos in the Homepage.

**The *TodoItem* component** - *TodoItem* widget is stateless for the moment. It takes as parameter a *Todo* instance and takes care of displaying it. *TodoItem* widget does not access the state. The todo to be displayed is, indeed, passed by the parent widget (the *TodoView*). However, *TodoItem* widget needs to write the state once the checkbox is tapped. For the moment, the *Checkbox* widget is just showing the value of the *completed* field and its *onChange* function is still empty. When the checkbox is tapped, a change into the corresponding *Todo*'s *completed* field should be fired and a rebuild of the *TodoItem* widget performed. In order to do so, *TodoInheritedData* widget should provide a state changing function for the *completed* field. The process to be done is the same exposed in the previous paragraph. Into the *TodoProvider* stateful widget a new function, called *onSetCompleted*, is created. This function takes as parameter the *id* of the todo to be changed and the new value for the *completed* field.

**Source Code 2.28:** Todo app - *InheritedWidget* - *TodoProvider* widget *onSetCompleted* function implementation

```

void onSetCompleted(int id, bool completed) {
    //control the todo's existence
    assert(todoExists(todos, id) == true, 'No todo with id : \${id}');
    //change the state
    setState(() {
        todos = todos.map((todo) {
            if (todo.id == id) {
                return Todo(
                    id: id,
                    name: todo.name,
                    description: todo.description,
                    completed: completed);
            } else {
                return todo;
            }
        }).toList();
    });
}

```

In the *onSetCompleted* function, *todos* list is scanned using the *map* method. Once the searched todo is found, its *completed* value is updated. Calling the *onSetCompleted* method on the *TodoProvider* stateful widget causes the *build* method to run again and to substitute the current *TodoInheritedData* widget with a new, updated, one. As before, the function is passed from the *TodoProvider* widget to the *TodoInheritedData* widget, on its creation. In this way, the function is made accessible down the tree. It is now possible to call *onSetCompleted* function inside the *onChanged* field of the *TodoItem*'s *Checkbox*.

**Source Code 2.29:** Todo app - InheritedWidget - *TodoItem*'s *Checkbox* *onChanged* field implementation

```

Checkbox(
    value: todo.completed,
    onChanged: (value) {
        //call the onSetCompleted method
    }
)

```



```

        TodoInheritedData.of(context).onSetCompleted(todo.id, value!);
    }),

```

At this point is possible to visualize the *filteredTodos* list, change the filter and update Todo's *completed* field.

**The Stats component** - Stats widget is stateless. It just needs to read the part of the state concerning the stats. The nearest instance of the `TodoInheritedData` widget is retrieved using the *of* method and used to fill in the Text widget.

**Source Code 2.30:** Todo app - InheritedWidget - Stats component implementation

```

class Stats extends StatelessWidget {
  const Stats({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Stats");

    return Center(
      child:
        //retrive the value of the stats
        Text(TodoInheritedData.of(context).stats.toString());
    );
  }
}

```

**The TabSelector component** - The part of the state concerning the tab just includes one variable and is related to the `HomePage` only. The fact that a state management solution is being used does not mean that it has to be adopted to handle everything. An important aspect of the state management in medium-large applications is that, the core objective, still remains to handle things in the easiest way possible, as long as it works fine. There is no meaning in overcomplicating procedures that are easy to implement. Sometimes, indeed, for the parts of the state that can be referred as "local", meaning that they are relative to a small part of the application only, is not necessary to use complicated state management solutions. It is better to keep things simple and use the

tools that most adapt to the specific scenario. In our case, there are two ways to implement the `TabSelector` widget: use `setState` and stateful widgets or use `InheritedWidgets`. The simpler one is to use `setState` as proposed in Source Code 2.31 for more than one aspect. Firstly, it is a good practice to keep the global state of the application as small and clean as possible. The bigger and the more complicated it gets the messier becomes to avoid bugs. Secondly, it is simpler, in practice, to create a local variable and to handle it with `setState` and stateful widgets instead of adding a new variable to the `TodoInheritedData` widget, manage it using the `to` `TodoProvider` widget and access it in the `HomePage`. The `HomePage` is already a stateful widget and is built using the `tab` variable. It is sufficient to add a new tab changing function to accomplish the task. This new function, called `onTabChange`, takes a `int` value as parameter and uses the `setState` method to update the `tab` variable. This `int` value refers to the index of the tapped element inside the list of `BottomNavigationBarItem` widgets provided to the `items` field.

**Source Code 2.31:** Todo app - `InheritedWidget` - `HomePage`'s `onTabChange` function implementation

```
TabState tab = TabState.todos; // new variable inserted in the HomePage

void onTabChange(int index) {
  setState(() {
    tab = TabState.values.elementAt(index);
  });
}
```

However, the function `onTabChange`, needs to be called in the `TabSelector` widget (and not in the `HomePage`). The easiest way is to pass it, together with the `tab` variable, as parameter and use it in the `BottomNavigationBar`'s `onTap` field.

**Source Code 2.32:** Todo app - `InheritedWidget` - `TabSelector` component implementation

```
class TabSelector extends StatelessWidget {
  final TabState currTab; // new parameter
  final Function(int) onTabChange; // new parameter
```

```

const TabSelector(
  {Key? key, required this.currTab, required this.onTabChange})
  : super(key: key);

@override
Widget build(BuildContext context) {
  print("Building Tab Selector");

  return BottomNavigationBar(
    currentIndex: TabState.values.indexOf(currTab), //used here
    onTap: onTabChange, //used here
    items: (...)
  );
}
}

```

It is now possible to switch from tabs. All the base functionalities were implemented. The whole process was fast and straight forward.

## Features addition

Here stats the development process described in subsection 2.1.2.

**Todo addition feature** - `TodoInheritedData` widget must provide a way of adding todos to the list. A new function is created, in the `TodoProvider` widget, and passed to the `TodoInheritedData` widget as parameter. This new function is called *onAddTodo* and takes two parameters (*name* and *description*).

**Source Code 2.33:** Todo app - InheritedWidget - `TodoProvider`'s *onAddTodo* function implementation

```

void onAddTodo(String name, String desc) {
  //generate a new unique id
  int newId = generateId(todos);
  //create the new todo
  Todo newTodo = Todo(

```

```

        id: newId,
        name: name,
        description: desc + " " + newId.toString(),
        completed: false);
    //perform the state change
    List<Todo> newList = List.from(todos);
    newList.add(newTodo);
    setState(() {
        todos = newList;
    });
}

```

After generating a new unique id, it creates a new *Todo* instance, called *newTodo*, with the *completed* field set to *false*. Adding the *newTodo* to the *TodoProvider*'s *todos* list requires a bit of workaround. The state of a stateful widget is immutable. It is a bit counterintuitive but, as we already discussed, in functional programming is generally easier to create new instances instead of mutating existing ones. Stateful widget's state can only be changed by the *setState* method. Unfortunately, the *add* method for lists, dart language provides, is of type *void* just adds the new value to the existing list's instance without returning anything. For this reason, directly calling the *add* method to the *TodoProvider*'s local *todos* list would have no effect. The *todos* list is immutable and cannot be changed. *TodoProvider*'s *todos* list must be completely replaced with a new instance containing the new todo. Firstly, a new temporary list, called *newList*, is created and populated with the elements present in the *todos* list. Then, the *newTodo* is added to this new list. At this point, is sufficient to replace the *todos* list with the new one inside the *setState* method.

To make the *onAddTodo* function accessible down the tree, is sufficient to add a new field in the *TodoInheritedData* widget and pass the *onAddTodo* function to it, on its creation.

**Source Code 2.34:** Todo app - *InheritedWidget* - *onAddTodo* function propagation

```

class TodoInheritedData extends InheritedWidget {

    final void Function(String,String) onAddTodo; // new variable

```

```
final List<Todo> todos;
final List<Todo> filteredTodos;
final void Function(VisibilityFilter) onChangeFilter;
final int stats;
final VisibilityFilter filter;

(...)

class TodoProvider extends StatefulWidget {
  @override
  Widget build(BuildContext context) {
    return TodoInheritedData(
      todos: todos,
      onChangeFilter: onChangeFilter,
      onAddTodo: onAddTodo, // passing the onAddTodo function
      onSetCompleted: onSetCompleted,
      filter: filter,
      child: widget.child,
    );
  }
}
```

In the `AddTodoPage`, a `TextButton` widget has been already set up to call the `onAddTodo` function once tapped. However, there is a small inconvenient. The `AddTodoPage` is accessed by pushing on top of the `HomePage` another route as shown in figure 2.5. The `AddTodoPage` is added as a child of the `MaterialApp` widget.

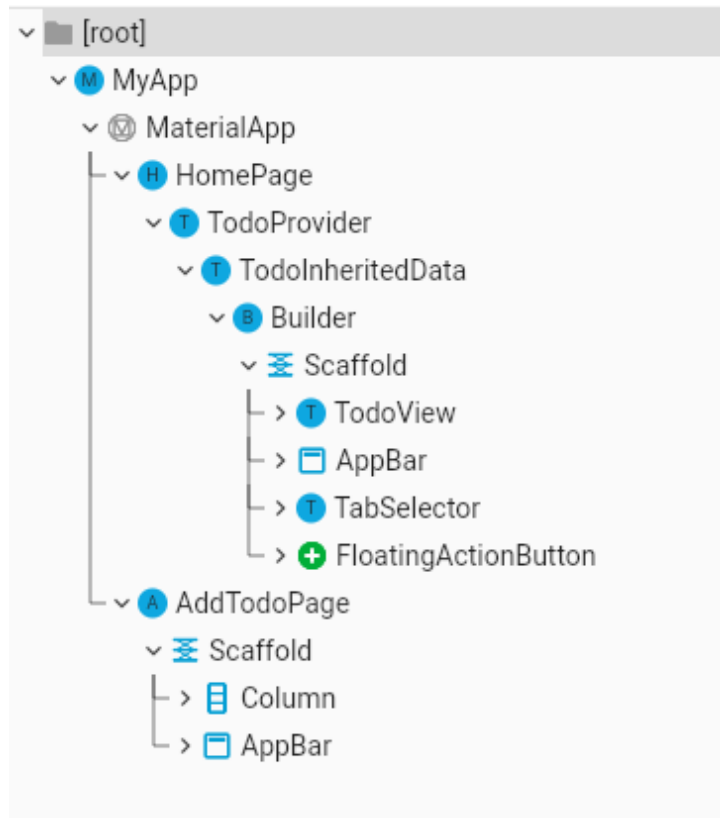


Figure 2.5: Shows the widgets tree structure in the AddTodoPage

The AddTodoPage is not a part of the subtree of the HomePage but is a standalone tree. There is no instance of TodoProvider widget as ancestor of the Scaffold widget present in the AddTodoPage. It is not possible, though, to call the *of* method as we did before. Indeed, calling the *of* method in a context where a TodoProvider widget is not present causes the assertion line (the one below) in Source Code 2.18 to return *false* and to rise a runtime error.

```
assert(result != null, 'No TodoInheritedData found in context');
```

The easiest method to proceed is to pass the *onAddTodo* function as a parameter to the AddTodoPage when it is pushed on top of the HomePage. A new parameter, called *addTodoCallback*, is added to the AddTodoPage.

**Source Code 2.35:** Todo app - InheritedWidget - AddTodoPage's callback function parameter creation

```
class AddTodoPage extends StatefulWidget {
  final void Function(String, String) addTodoCallback; // new parameter

  const AddTodoPage({Key? key, required this.addTodoCallback})
    : super(key: key);
}
```

Then, the `MaterialApp` is notified about the necessity of this new argument at the `AddTodoPage` creation. The argument is found inside the *context*, in a specific variable called *arguments*.

**Source Code 2.36:** Todo app - `InheritedWidget` - "`addTodo`" route parameters re-definition

```
routes: {
  . . .
  "/addTodo": (context) => AddTodoPage(
    // passing the onAddTodo function by argument
    addTodoCallback: ModalRoute.of(context)!.settings.arguments
      as Function(String, String)),
},
```

The *addTodoCallback* function is then used in the *onPressed* field of the `TextButton` widget in the `AddTodoPage`. Once the `TextButton` is tapped, the new todo is added to the list and the `AddTodoPage` is popped returning to the `HomePage`. Being the state changed the `HomePage` is rebuilt.

**Source Code 2.37:** Todo app - `InheritedWidget` - `AddTodoPage` *onPressed* field implementation

```
TextButton(onPressed: () {
  widget.addTodoCallback(textControllerName.text, textControllerDesc.text);
  Navigator.pop(context);
})
```

Raising the `TodoProvider` widget above the `MaterialApp` widget would not be a good solution. The higher the `TodoProvider` widget resides in the tree the more widgets are rebuilt on state changes. In this case it is easier to pass the callback function as parameter to the `AddTodoPage`.

**Todo updating feature** - A new function must be implemented in the `TodoProvider` widget and passed to the `TodoInheritedData` widget. This new function is called *onUpdateTodo* and takes three arguments: the *id* of the todo to be updated, the *newName* and the *newDesc*.

**Source Code 2.38:** Todo app - InheritedWidget - `TodoProvider`'s *onUpdateTodo* function implementation

```
void onUpdateTodo(int id, String newName, String newDesc) {  
  //control the todo's existence  
  assert(todoExists(todos, id) == true, 'No todo with id : \${id}');  
  //create a new list with the updated todo  
  List<Todo> newTodosList = todos.map((todo) {  
    if (todo.id == id) {  
      return Todo(  
        completed: todo.completed,  
        description: newDesc,  
        name: newName,  
        id: todo.id);  
    } else {  
      return todo;  
    }  
  }).toList();  
  //update the state  
  setState(() {  
    todos = newTodosList;  
  });  
}
```

The *onUpdateTodo* function checks if a todo matching the *id* exists. Then, for the same immutability concept we dealt with in the previous paragraph 2.30, a *newTodosList* is



created and populated with the elements of the *todos* list. Moreover, the todo with the corresponding id is updated with the new name and the new description. Finally, the *todos* list in the TodoProvider stateful widget is replaced with the *newTodosList* using the *setState* method. This new *onUpdateTodo* method is then made accessible down the tree adding a field to the TodoInheritedData widget.

**Source Code 2.39:** Todo app - InheritedWidget - *onUpdateTodo* function propagation

```
class TodoInheritedData extends InheritedWidget {

    final void Function(int, String,String) onUpdateTodo; // new variable
    final void Function(String,String) onAddTodo;
    final List<Todo> todos;
    final List<Todo> filteredTodos;
    final void Function(VisibilityFilter) onChangeFilter;
    final int stats;
    final VisibilityFilter filter;

    (...)

class TodoProvider extends StatefulWidget {

@override
Widget build(BuildContext context) {
    return TodoInheritedData(
        todos: todos,
        onChangeFilter: onChangeFilter,
        onAddTodo: onAddTodo,
        onSetCompleted: onSetCompleted,
        onUpdateTodo: onUpdateTodo, // passing the onUpdateTodo function
        filter: filter,
        child: widget.child,
    );
}
```

For the same problem faced during the implementation of the todo addition feature,

also in this case, the *onUpdateTodo* function must be passed to the new route (no *TodoProvider* present in this context) as parameter. A new variable is added to the *UpdateTodoPage*, beside the already existent one, called *callback*. This new variable is of type *Function* taking two *Strings* as arguments (the id will be already set up by the calling page).

**Source Code 2.40:** Todo app - *InheritedWidget* - *UpdateTodoPage* callback function parameter creation

```
class UpdateTodoPage extends StatefulWidget {
  final Todo todo;
  final void Function(String, String) callback; // new variable

  const UpdateTodoPage({Key? key, required this.todo,
    required this.callback})
    : super(key: key);

  (...)
}
```

We are ready now to push the *UpdateTodoPage* on top of the *Homepage* when the *InkWell* widget (inside the *TodoItem* widget) is tapped. However, there is a small extra step to perform before proceeding. *Flutter Navigator*, indeed, allows to pass a single object as argument between routes. In this case, besides the *onUpdateTodo* function also a *todo* instance must be passed to the *UpdateTodoPage*. For this reason, a wrapper class is created with the name *UpdateTodoPageArguments*.

**Source Code 2.41:** Todo app - *InheritedWidget* - *UpdateTodoPageArguments* class implementation

```
class UpdateTodoPageArguments {
  final Todo todo;
  final void Function(String, String) updateState;

  UpdateTodoPageArguments({required this.todo, required this.updateState});
}
```

Inside the InkWell's *onTap* function ,the corresponding todo and the *onUpdate* function are wrapped into an object of type `UpdateTodoPageArguments`. This object is then passed to the new route.

**Source Code 2.42:** Todo app - InheritedWidget - Using a `UpdateTodoPageArguments` instance to pass argument between routes

```
Navigator.pushNamed(context, "/updateTodo",
//passing the the state changing function using a wrapper class
  arguments: UpdateTodoPageArguments(
    todo: todo,
    updateState: (String newName, String newDesc) {
      TodoInheritedData.of(context, aspect: 0)
        .onUpdateTodo(todo.id, newName, newDesc);
    }));
```

It is necessary to specify to the `MaterialApp` widget where, the two parameters (necessary for the `UpdateTodoPage` creation), will be situated. As before , they are putted in a specific variable, inside the *context* object, called *arguments*.

**Source Code 2.43:** Todo app - InheritedWidget - "*updateTodo*" route re-definition

```
routes: {
  "/": (context) => const HomePage(),
  "/updateTodo": (context) => UpdateTodoPage(
    todo: (ModalRoute.of(context)!.settings.arguments
      as UpdateTodoPageArguments)
    .todo,
    callback:
//access the wrapper class to populate the callback parameter
    (ModalRoute.of(context)!.settings.arguments
      as UpdateTodoPageArguments)
    .updateState,
  ),
```

---

Now that the *onUpdateTodo* function is accessible in the *UpdateTodoPage* it is time to call it inside the *TextButton* *onPressed* field.

**Source Code 2.44:** Todo app - *InheritedWidget* - *UpdateTodoPage* *onPressed* field implementation

```
TextButton(onPressed: () {  
  //call the onUpdateTodo function  
  widget.callback(textControllerName.text, textControllerDesc.text);  
  Navigator.pop(context);  
},
```

At this point, once the user taps the confirm button, the page pops, the corresponding todo updates and the *HomePage* rebuilds.

## Rendering optimizations

I spent some hours trying to figure out how to make the single *TodoItem* widget rebuild, after a non-structural change occurs. When a non-structural change occurs, may be instresting, tough, to limitate the tree rebuilding to widgets affected by the mutation only. For example, when the *Checkbox* inside a *TodoItem* widget is tapped, would be nice to rebuild the *TodoItem* widget only, and not the entire *TodoView* widget. After some attempts, I realized that it was just not feasible using *InheritedWidgets* alone. *InheritedWidgets*, indeed, do not offer this possibility at all. Every time a widget accesses the state in the *TodoProvider*'s subtree, using the *of* method, it is registered as *listener* for state changes. Once a state change occurs, there are only two possibilities: notify all listeners and rebuild them or notify none. In other words when a state change occurs, and it must be visualized, the entire *TodoProvider*'s subtree is rebuilt unconditionally. Flutter framework, however, offers a particular widget, called *InheritedModel*, to handle this kind of scenario. *InheritedModel* works as *InheritedWidget* except for the fact that, when a widget accesses the state, (calling the *of* method) it must provide also a new additional parameter, called *aspect*. The *aspect* parameter can be whatever object. For

example a String or a Int, but also a more complex data structure. The *aspect* parameter identifies which part (or parts) of the state the widget is registering to. With this new additional tool is possible to achieve the partial rendering we were looking for. Indeed, with InheritedModel, widgets are rebuilt based on the changed aspect of the state. If a widget registered for a particular aspect and a state mutation, not affecting that aspect, occurs, the widget is not rebuilt. However, the entire logic defining which aspect of the data changed (when a state transition occurs) must be implemented by the programmer. The extension to InheritedWidget is substituted with the extension to the InheritedModel, in the TodoInheritedData class.

**Source Code 2.45:** Todo app - InheritedModel - extension to InheritedModel

```
class TodoInheritedData extends InheritedModel<int> {
```

I decided to use Ints in order to identify aspects. In particular, widgets that need to rebuild on *filteredTodos* list structural change, register to the aspect identified with the number 0. Widgets that do never need to rebuild register to the aspect identified with number 1. Widgets that need to rebuild when a non-structural change affecting the specific Todo with id n occurs register to the aspect identified with the number n. (no Todos will have id with value 0 or 1. This is a convention I used to keep things simple. Other, more complex structure, could be used to avoid this behaviour). At this point, the method *of*, in the TodoInheritedData widget, should be updated taking into account the *aspect* parameter. Moreover, the *result* variable should be populated with the *inheritFrom* static method belonging to the InheritedModel class, instead of the *dependOnInheritedWidgetOfExactType* static method belonging to InheritedWidget class.

**Source Code 2.46:** Todo app - InheritedModel - TodoInheritedData's *of* method implementation

```
//add the aspect argument
static TodoInheritedData of(BuildContext context, {required int aspect})
{
  final TodoInheritedData? result =
    //calling the inheritFrom method using the aspect parameter
    InheritedModel.inheritFrom<TodoInheritedData>(context,
```

```

        aspect: aspect);
    assert(result != null, 'No TodoInheritedData found in context');
    return result!;
}

```

All the lines of code accessing the state with the *of* method must now be changed taking into account the new implementation and the new *aspect* argument.

```

TodoInheritedData.of(context, aspect: aspect)

```

In particular, the `TodoView` widget will pass as *aspect* argument the number 0 declaring that should be notified (and rebuild) only when a structural change occurs. Instead, `TodoItem` widgets will pass the corresponding `Todo`'s *id* in the *aspect* parameter. Now that every widget is registered to the desired aspect of the data, it is necessary to “teach”, the `TodoInheritedData` widget ,how to recognize aspects’ changes. To do so, `InheritedModel` provides a method called *updateShouldNotifyDependent* that is similar to the `InheritedWidget`'s one, *updateShouldNotify* , but takes as argument also a `Set` of ints called *dependencies* (aspects). Once a transition occurs this method is called once for every widget that registered to state changes. The *dependencies* variable will contain all *aspects* the widget registered to (only one for every widget in our case).

**Source Code 2.47:** Todo app - `InheritedModel` - `TodoInheritedData`'s *updateShouldNotifyDependent* method implementation

```

@override
bool updateShouldNotifyDependent(
    TodoInheritedData oldWidget, Set<int> dependencies) {
    //calculate the length of the current filtered list
    int currLen = filteredTodos.length;
    //calculate the length of the previous filtered list
    int prevLen = oldWidget.filteredTodos.length;
    //if updateShouldNotifyDependent is called in a structural
    // dependent widget and a structural change occurred
    bool structureRebuildlen = (dependencies.contains(0) &&

```

```

    currLen != prevLen);
if (structureRebuildlen == true) {
  //rebuild
  return true;
} else {
  //compute the list of ids in the current filtered list
  List<int> currIds = filteredTodos.map((todo) => todo.id).toList();
  //compute the list of ids in the previous filtered list
  List<int> prevIds =
    oldWidget.filteredTodos.map((todo) => todo.id).toList();
  //compute if ids changed
  bool sameIds = listEquals(currIds, prevIds);
  //computer if updateShouldNotifyDependent is called in a
  // structural dependent widget and a structural change occurred
  bool structureRebuildcomp = (dependencies.contains(0) && !sameIds);
  if (structureRebuildcomp == true) {
    //rebuild
    return true;
  } else {
    //create an array of booleans
    List<bool> components = [];
    //for every todo in the current filtered list
    for (var element in filteredTodos) {
      //add the boolean && between
      components.add(
        //if updateShouldNotifyDependent is called in a widget
        // that registered to the aspect with that id
        dependencies.contains(element.id)
        &&
        // if the element with that id in the previous
        // filtered list is different
        !oldWidget.filteredTodos.contains(element));
    }
    //apply the or operator between all elements in the list
    bool res = components.fold(false,
      (bool previousValue, bool element) => previousValue || element);
  }
}

```

```

        return res;
    }
}

```

This method was tough to code. The method's pseudocode is presented down below.

**Source Code 2.48:** Todo app - InheritedModel - TodoInheritedData's *updateShouldNotifyDepended* method pseudocode

```

if( widgetRegisteredForStructuralChange && structuralChangeOccured){
    return true;
}else{
    if( widgetRegisteredForSpecificTodoChange && thatTodoChanged){
        return true;
    }else{
        return false;
    }
}

```

I propose now two practical examples to clarify a bit the *updateShouldNotifyDepended* behaviour.

**Practical example 1 -** Suppose to have a list of todos containing two todo instances, one with id 38 and one with id 121. In the HomePage there is a TodoView widget containing two TodoItem widgets. TodoView widget calls the *of* method in order to access the state passing the int value 0 as parameter. The two TodoItem widgets call the *of* method in order to access the state passing their todo's id value as parameter. Suppose now to add a new todo in the list using the AddTodoPage. The *updateShouldNotifyDepended* method is called once for every widget that access the state. Note that also the TabSelector and the VisibilityFilterSelector widgets access the state using the *of* method but their are not considered in this example. So, the *updateShouldNotifyDepended* method is called once for the TodoView widget, with dependencies value equal to 0. It is also called once for every TodoItem widget with dependencies value equal to 38, in one case, and equal to 121, in the other. Before actually rebuilding any widget the framework executes



all the *updateShouldNotifyDependent* method calls. We start analyzing the call for the `TodoItem` widget with id 38 with reference to the pseudocode defined in Source Code 2.49. In this case a structural change occurred ( we added a todo) but the widget did not registered for structural changes ( dependencies do not contains 0). Moreover, the widget registered for changes in the todo with id 38 but no changes occurred in that todo. The function returns false and the widget is not rebuilt. The same happens for the *updateShouldNotifyDependent* methods execution of the `TodoItem` widget with id 121. In the *updateShouldNotifyDependent* method execution for the `TodoView` widget, instead, the dependencies list contains the value 0 (and only that). In this case the `TodoView` widget registered for structural changes and a structural change occurred (the new list is longer than the old one). The *updateShouldNotifyDependent* method returns true and the widget is rebuilt creating a new `TodoView` widget composed by three `TodoItem` widgets this time.

**Practical example 2 -** Suppose to have a list of todos containing two todo instances as before, one with id 38 and one with id 121. In the `HomePage` there is a `TodoView` widget containing two `TodoItem` widgets. `TodoView` widget calls the *of* method in order to access the state passing the int value 0 as parameter. The two `TodoItem` widgets call the *of* method in order to access the state passing their corresponding todo's id value as parameter. Suppose now to tap on the `TodoItem` widget's checkbox with id 38 in order to change its *completed* value. As before the *updateShouldNotifyDependent* method is called once for every widget that access the state. The *updateShouldNotifyDependent* method execution regarding the `TodoView` widget returns false because the second if in the Source Code 2.49 evaluates to false due to the fact that the widget did not registered for specific todo's changes. The `TodoView` widget is not rebuilt then. In the *updateShouldNotifyDependent* method execution regarding the `TodoItem` widget with id 121 the part that leads the entire method to return false is the second expression in the second if statement. Indeed, the todo with id 121 did not changed with respect to the one contained in the previous state. The `TodoItem` widget with id 121 is consequently not rebuilt. The execution of the *updateShouldNotifyDependent* method concerning the `TodoItem` with id 38, instead, return true. The second condition is, indeed, satisfied by the fact that the widget registered for a specific todo's change and also that todo changed. The todo with id 38 is, indeed, changed with respect to the todo with id 38 in the previous state. This leads the `TodoItem` widget with id 38 to rebuild leaving all the other widgets unchanged.

At this point , when the `TodoItem`'s checkbox is tapped the single `TodoItem` widget

is rebuilt. However, no visual changes are shown. The widget rebuilds with the same information as before. This is due to the fact that, the *build* method, populates its internal widgets based on a local *todo* variable. This variable is populated on the *TodoItem* widget's creation with a *Todo* instance provided by the parent widget(*TodoView*). Indeed, when the *TodoView* widget instantiates *TodoItems* in its *ListView*, it creates a copy of the corresponding *Todo* before passing it to the constructor. Even if we changed the information contained in the *TodoInheritedData* widget, the *TodoItem* widget do not see any difference. Its local *todo* variable, indeed, did not change. The fact that, before the optimizations, *TodoItem* widgets rebuilt correctly comes from the fact that the transition of the state caused actions leads the entire *TodoView* widget to rebuild. The consequence was that *TodoItems* were destroyed and created again using new copies of the data coming from the *TodoInheritedData* widget.

To recap, the performance optimization we were looking for were achieved successfully but an issue, regarding the synchronization of the data, arised. The *TodoItems* widget sees a screenshot of the state different from the one seen by the rest of the application. This is a really bad behavior and is caused by the fact that, sometimes, during programming, more than one level of information caching is required or used to avoid effort in coding and performance issues. In other words, a local copy of the data is kept and referred to in case of data access in order to optimize the accesses in the main storage that can become quite expensive in large scenarios. A great example of that is the local copy of the database's data used in many applications. Is more effective to fetch data from the database, save them locally, manipulate this local copy and only in case of real necessity access again the database to store them or retrieve other data. In large applications (but also in small ones like in this cases) more than one level of data caching is used. Particular attention is required to handle those levels to avoid inconsistency in what is visualized and the real data. In this case the *filteredTodos* list actually changed but the UI did not reflect this change. The problem was generate by the fact that a local copy of the real *Todo* instance was passed to the *TodoItem* widget. Instead, the "correct" way of handling this scenario is to pass the id of the *Todo* in the constructor and then use this id to look up for the *Todo* instance in the centralized state (the *TodoInheritedData*). This of course will require more computational effort but will guarantee also a lot more stability and robustness. Therefore, *TodoItem* widget's local variable of type *Todo* is replaced with a new int variable called *id* that represents the id of the *Todo* the widget is visualizing. In the *build* method, then, the corresponding *Todo* is looked up.

**Source Code 2.49:** Todo app - InheritedModel - accesing the state into *TodoItem* component

```

class TodoItem extends StatelessWidget {
  final int id; // Todo variable replaced with a int one

  const TodoItem({Key? key, required this.id}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    // getting the todo instance from the state
    final Todo todo = TodoInheritedData.of(context, aspect: id)
      .todos
      .where((element) => element.id == id)
      .first;
  }
}

```

At this point the application is working as intentioned and the rendering optimizations were successfully accomplished.

## Conclusions

Table 2.1 reports some measurements taken from the InheritedWidget's implementation process. The *lines of code* column represents the lines of code added or updated with respect to the shared project structure proposed in subsection 2.2.1. The *time* column represents the time spent in order to implement the corresponding subprocess. The unit of measure **h** stands for hours and **m** stands for minutes. The *lines-time ratio* column represents the average number of lines written in a minute. The *classes* column represents the number of created classes in each subprocess.

Measurement for InheritedWidget process

	lines of code	time	lines/time ratio	classes
base functionalities	86	2-3 h	0.57 l/m	2
feature addition	43	20-30 m	1.72 l/m	1
rendering optimization	49	8-10 h	0.092 l/m	0

Table 2.1: InheritedWidget measurements table

Figure 2.6 represents a pie chart showing the percentage of lines of code written in each implementation's process, including the one regarding the shared structure. The whole process is quite balanced in term of lines of code. The 64% of the code is used to produce the presentation layer and the remaining 36% is used to manage the state and its optimizations. Considering the fact that the UI is kept minimal truncating the necessary lines of code accentuates even more the fact that the state management took less than a half of the entire written code.

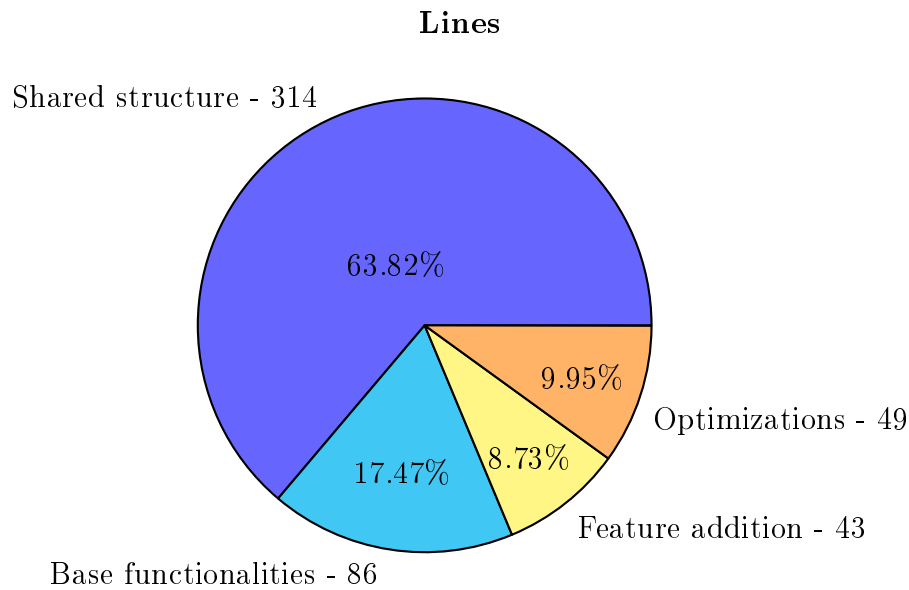


Figure 2.6: Shows the pie chart regarding the lines of code spent in each subprocess for the InheritedWidget implementation

Figure 2.7 represents a pie chart showing the percentage of time spent in each implementation's process. Notice that the optimizations process took more than the 75% of the entire time.

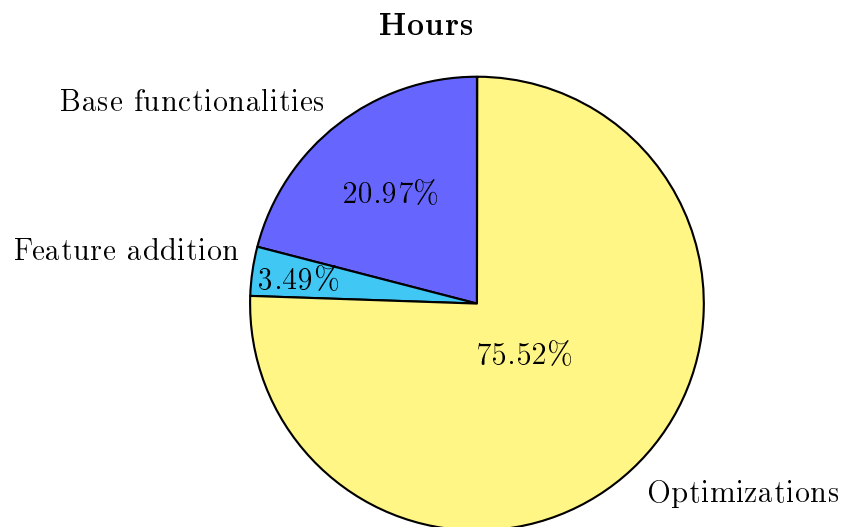


Figure 2.7: Shows the pie chart regarding the hours spent in each subprocess for the InheritedWidget implementation

Figure 2.8 shows the final folders structure for the InheritedWidget implementation. The only file added to the original folders structure is the `todo_provider.dart` file.

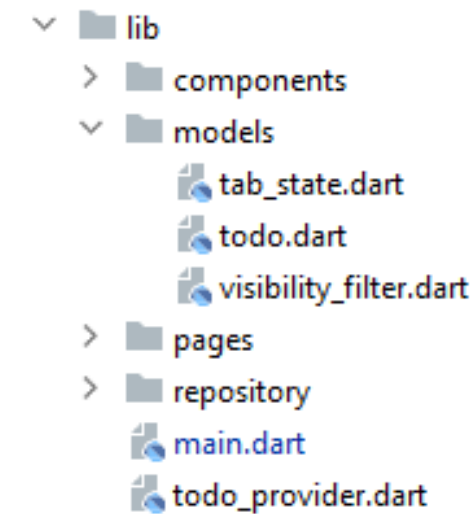


Figure 2.8: Shows the final folders structure for the InheritedWidget implementation of the Todos app

Figure 2.13 represents the widget's tree structure for the InheritedWidget final application. Notice the `TodoProvider` widget, situated below the `HomePage`, providing an instance of the `TodoInheritedData` to the subtree.

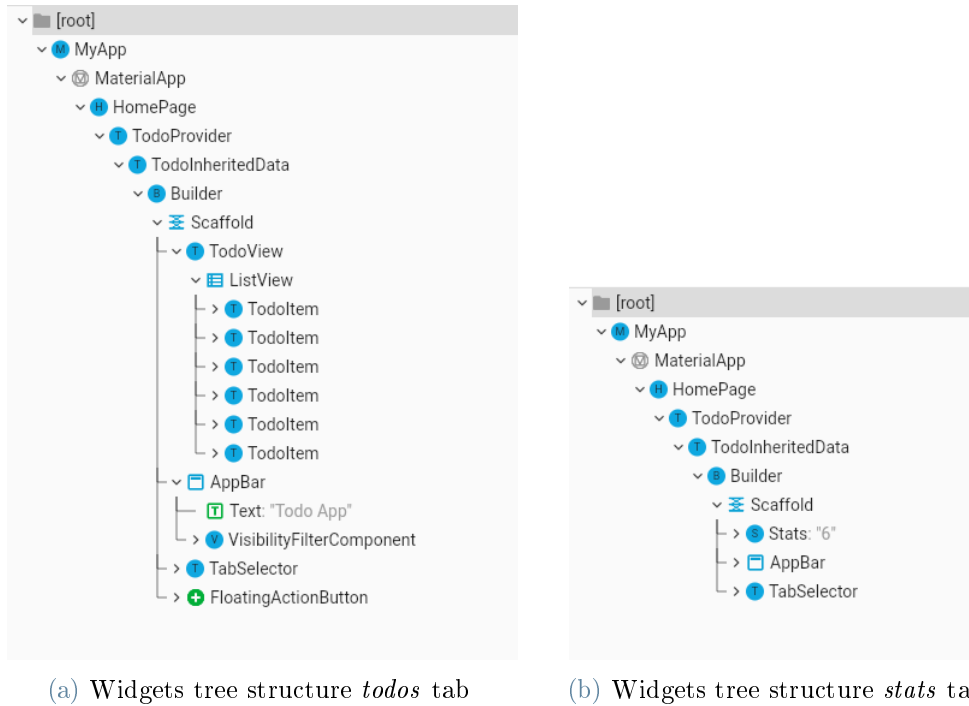


Figure 2.9: Shows the widgets tree structure for InheritedWidget Todos app

### 2.2.3. Redux implementation

This section implements the Todo application using the Redux package in order to handle the state.

### Base functionalities

**The AppState** - Redux solution requires the state to be centralized in a unique location. A model for this centralized component must be defined in order to group up all the subparts. Subparts of the state regarding the filter and the tab have been already modelled in the implementation of the shared parts in paragraph 2.2.1 in Source Code 2.2 and 2.3. They are used now to compose a new class, called AppState, that groups all the subparts in a unique place throughout the entire application.

**Source Code 2.50:** Todo app - Redux - AppState model implementation

```
class AppState {  
  
    VisibilityFilter visibilityFilter;  
    List<Todo> todos;  
    TabState tabState;  
  
    AppState({this.todos=const [],  
             this.tabState= TabState.todos,  
             this.visibilityFilter= VisibilityFilter.all});  
}
```

Notice that the list of filtered todos is not contained in the AppState model. When the Redux solution is used, indeed, the centralized state is kept as simple as possible and the parts of the state that can be computed or derived should be omitted. The filtered list of todo will be computed in the presentation layer when needed. This approach, however, can introduce redundant computations due to the fact that the filtered list is calculated at every widget's build. This is where Selectors come into play; they propose a mechanism based on the memoization technique in order to reuse precomputed values. This aspect will be deeper investigated later.

**The actions** - In order to mutate the state is necessary to define *actions*. Actions are processed by reducers to produce new states. Actions are just instances of predeclared classes. We start defining the action's classes needed to change the state regarding the list of todos. As usual, the first two features to be implemented are the fetching process and the setting of the *completed* field of a specific todo. Due to the way Redux works, asynchronous actions are handled by Middlewares. Reducers, indeed, are pure functions and are not suited for handling asynchronous code. Two actions are defined just for the fetching process. One is called *LoadTodoAction* and will be intercepted by the middleware which takes care of fetching todos from the database. The second is called *LoadTodoSucceededAction* and carries the list of fetched todos. When the fetching process in the middleware terminates, a new *LoadTodoSucceededAction* is emitted and handled by the AppState's reducers.

**Source Code 2.51:** Todo app - Redux - actions implementation for the fetching process

```
class LoadTodoAction{
    @Override
    String toString(){
        return "LoadTodoAction";
    }
}

class LoadTodoSucceededAction{
    List<Todo> todos;
    LoadTodoSucceededAction(this.todos);

    @Override
    String toString(){
        return "LoadTodoSucceededAction";
    }
}
```

Another action class is created in order to handle the setting of the *completed* field. In this case the action is synchronous and is directly handled by reducers. This new action is called *SetCompletedAction* and contains the id of the todo to be changed and the new value for the *completed* field.

**Source Code 2.52:** Todo app - Redux - SetCompletedTodoAction implementation

```
class SetCompletedTodoAction {
    final int id;
    final bool completed;

    SetCompletedTodoAction(this.id, this.completed);

    @Override
    String toString(){
        return "SetCompletedTodoAction";
    }
}
```



Two more actions are needed in order to handle the tab's and the visibility filter's changes. They are called respectively *SetTabAction* and *SetVisibilityFilterAction*. They contains the new *tab* value and the new *filter* value to be set.

**Source Code 2.53:** Todo app - Redux - SetTabAction and SetVisibilityFilterAction implementation

```
class SetTabAction{
    final TabState newtab;

    SetTabAction(this.newtab);

    @Override
    String toString(){
        return "SetTabAction";
    }
}

class SetVisibilityFilterAction{
    VisibilityFilter filter;

    SetVisibilityFilterAction(this.filter);

    @Override
    String toString(){
        return "SetVisibilityFilterAction";
    }
}
```

**Reducers** - Is the turn now for reducers's definition. They link actions with new states. Even if the usage of the Redux state management solution requires the centralization of the state in a unique component, the state's logic can be in any case split up in subparts. It is like a tree with a single root where the root is represented by the AppState's reducer. It can split up in many sub-reducers and every one of them can further split up into other sub-reducers. Therefore, the state is stored in single place, but its pieces can still

be segmented and managed separately and independently. During the reasoning process it is easier to break the whole state into smaller pieces step by step using a top-down approach. However, in the implementation process, a bottom-up approach is usually taken. This is due to the fact that, during the implementation process, smaller bricks are required to build bigger components. In this presentation, for example, is not possible to define directly the AppState's reducer even if, logically, it should be the first reducer to be implemented. The AppState's reducer is composed by multiple sub reducers, in our case three. There is a reducer for the list of todos, a reducers for the filter and a reducer for the tab.

**The todoReducer** - The reducer for the list of todos needs to handle two actions, the *LoadTodoSucceededAction* and the *SetCompletedTodoAction*. The *todoReducer* is a combination of two subreducers both handling a specific action. As we already said, reducers are pure functions. They take the previous state and an action and return the next state. The reducer for the *LoadTodoSucceededAction* is called *setLoadedTodo* and just returns the list contained in the received action.

**Source Code 2.54:** Todo app - Redux - LoadTodoSucceededAction reducer implementation

```
List<Todo> _setLoadedTodo(List<Todo> todos,
  LoadTodoSucceededAction action) {
  return action.todos;
}
```

The reducer for the *SetCompletedTodoAction* is called *setCompletedTodo* and takes care of searching in the current list of todos the todo matching the id contained in the action. Once found, it is updated and a new instance of the whole list is created and returned. The necessity to create another instance for the list comes from the fact that, in order to recognize a state change, Redux needs to identify differences between the current state and the previous one. If we just update the list it would result to be equal to the previous one and the transition would not be recognised.

**Source Code 2.55:** Todo app - Redux - SetCompletedTodoAction reducer

```
List<Todo> _setCompletedTodo(List<Todo> todos,
    SetCompletedTodoAction action) {
    List<Todo> newList= todos.map((todo) => todo.id == action.id
        ? Todo(
            id: action.id,
            name: todo.name,
            description: todo.description,
            completed: action.completed)
        : todo).toList();

    return List.from(newList);
}
```

Now that all reducers related to the list of todos have been implemented we use some tools, the Redux package provides, in order to combine them in a single one binding the received actions to the correct sub-reducer. These tools are the *combineReducers* function and the *TypedReducer* class. The *TypedReducer* class is, indeed, a typed class that helps avoiding nested if-else structures which can generate lot of boilerplate and code unreadability. It binds a specific action to a reducer. *combineReducers*, instead, is a function that creates a new reducer composing sub-reducers provided in the form of *TypedReducers*. The two previously defined reducers are now merged into a single one called *todosReducer*.

**Source Code 2.56:** Todo app - Redux - todoReducer implementation using *combineReducers* function

```
final todoReducer = combineReducers<List<Todo>>([
    TypedReducer<List<Todo>, LoadTodoSucceededAction>(_setLoadedTodo),
    TypedReducer<List<Todo>, SetCompletedTodoAction>(_setCompletedTodo),
]);
```

The alternative would have been to write the *todosReducer* as presented in Source Code ???. The output is the same but the code is clearly less readable.

**Source Code 2.57:** Todo app - Redux - todoReducer implementation using the traditional way

```
final todosReducer = (List<Todo> todos, action) {
  if (action is LoadTodoSucceededAction) {
    return _setLoadedTodo(todos, action);
  } else if (action is SetCompletedTodoAction) {
    return _setCompletedTodo(todos, action);
  } else {
    return state;
  }
};
```

**The tab's reducer and the visibility filter's reducer -** The process is the same as before. Two reducers, called *setTabState* and *setVisibilityFilter*, are created in order to handle the actions of type *SetTabAction* and *SetVisibilityFilterAction* respectively. In both cases the value contained in the action is used to produce a new state. Both of them are used to create two other reducers called *tabReducer* and *visibilityFilterReducer* using the *combineReducers* function introduced earlier. In this case the usage of the *combineReducers* function wasn't really necessary by the fact that it combines only one reducer. However, in case new actions are introduced it gets handy.

**Source Code 2.58:** Todo app - Redux - tabReducer and visibilityFilterReducer implementation

```
//reducer for the tab
TabState _setTabState(TabState state, SetTabAction action){
  return action.newtab;
}
//combineReducers for the tab
final tabReducer= combineReducers<TabState>([
  TypedReducer<TabState, SetTabAction>(_setTabState),
]);
```

```
//reducer for the filter
VisibilityFilter _setVisibilityFilter(
    VisibilityFilter oldState, SetVisibilityFilterAction action) {
    return action.filter;
}
//combineReducers for the filter
final visibilityFilterReducer = combineReducers<VisibilityFilter>([
    TypedReducer<VisibilityFilter, SetVisibilityFilterAction>(
        _setVisibilityFilter)
]);
```

**The AppState reducer** - All the basic bricks have been implemented and can be used now to create the biggest reducer; the AppState's reducer. It is a function that takes the current *AppState* and an action. It then creates a new AppState instance using the sub-reducers it is composed of. Every sub-reducer processes the received action in order to investigate the necessity of perform a transition in the part of the state it handles.

**Source Code 2.59:** Todo app - Redux - appStateReducer implementation

```
AppState appStateReducer(AppState appState, action) {
    return AppState(
        todos: todoReducer(appState.todos, action),
        tabState: tabReducer(appState.tabState, action),
        visibilityFilter: visibilityFilterReducer(appState.visibilityFilter,
            action));
}
```

**The Middleware** - All the necessary elements in order to start accessing the state in the presentation layer are settled up but the way in which todos are fetched from the database is not clear yet. Two actions were set up for this purpose but only one has been handled by a reducer. The process of fetching todos from the database is not immediate. It is asynchronous with respect to the application workflow. Reducers are not suited for handling asynchronous code, they need to be pure and as simple as possible. There

are many ways, in practice, to deal with asynchronous code using Redux but, the most correct one (and also the one proposed in the documentation) is to use Middlewares. Middlewares has been introduced HERE [RIFERIMENTO](#). They act as a sort of proxy between actions and reducers. One or more middlewares can be set to be executed on actions' emission. They are used to handle asynchronous code but also side effects generated by actions. In our case, an action of type *LoadTodoAction* has been defined but is not handled by any reducer yet and it is ignored once received. However, it will pass through one or more middlewares before reaching the reducers. It is necessary to set up a middleware that intercepts it and starts the fetching process. A middleware is just a function that takes three parameters: the *store*, an *action* and the *next* dispatcher. It processes the action, probably accessing the store, and then passes the action to the next middleware. A new middleware function is defined and called *loadTodoMiddleware*. It checks if the dispatched action is of type *LoadTodoAction* and, in case it is, starts to load the todos from the database. Once the fetching process is completed it dispatches an action of type *LoadTodoSucceededAction* that contains the list of fetched todos. We previously set up a specific reducer in order to handle this type of action in the AppState reducer.

**Source Code 2.60:** Todo app - Redux - loadTodosMiddleware middleware implementation

```
void loadTodosMiddleware(Store<AppState> store, action,
NextDispatcher next) {

    if (action is LoadTodoAction) {
        TodoRepository.loadTodos().then((todos)
            {store.dispatch(LoadTodoSucceededAction(todos));} );
    }
    next(action);
}
```

All the ingredients are now available to start composing our UI.

**Making the state accessible** - Redux solution uses Provider widgets to make the state accessible down the widgets tree. The state is unique and, therefore, should be placed in the root of the widgets tree, otherwise, some parts of the tree would not be

covered by its accessibility. To do so, a `StoreProvider` widget is positioned at the root of app, right below the `MyApp` widget. An object of type `Store` must be provided to the `StoreProvider` widget, in the `store` field. The typed class `Store` is provided by the `Redux` package. In our case, the global state is modelled by the `AppState` class. The `Store` class constructor takes three parameters. The reducer for the `AppState`, an `AppState` instance that identifies the initial state and a list of middlewares. In our case a single middleware is used. In order to fetch todos at the application start we will use the `init` method of stateful widgets. The `HomePage` is already stateful and its `init` method is used in order to dispatch the first action : the `LoadTodosAction`. For simplicity the function to be executed in the `init` method is passed from the `MyApp` widget, where the store is already available, to the `HomePage` using a newly created parameter.

**Source Code 2.61:** Todo app - Redux - makes the Store accessible using a `StoreProvider` widget

```
void main() {
  WidgetsFlutterBinding.ensureInitialized();
  runApp(MyApp(
    store: Store<AppState>(appStateReducer, //pass the AppState's reducer
      initialState: AppState(), middleware: [loadTodosMiddleware]));
  )

class MyApp extends StatelessWidget {
  final Store<AppState> store; //new parameter

  const MyApp({Key? key, required this.store}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("Building Material App");
    return StoreProvider(// use a StoreProvider widget
      store: store, //use the new parameter here
      child: MaterialApp(initialRoute: "/",
        routes: {
          //pass the todos's fetching action to the HomePage
          "/": (context) => HomePage(onInit: (){
```

```

        store.dispatch(LoadTodoAction());
      },),
      (...),
    },
  ),
);
}
}

```

Inside the `HomePage`, the `initState` method is set up in order to dispatch a `LoadTodoAction` using the function passed as parameter by the `MaterialApp` widget. In order to access the store, a `StoreConnector` widget is used. A `StoreConnector` widget takes two functions in its `converter` and `builder` fields. The `converter` function takes the state and creates a viewmodel containing the minimal information necessary to build the widget. The `builder` function actually uses the viewmodel in order to create the widget. The viewmodel is really important because identifies the prospective from which, the widget, is looking at the centralized state. If the viewmodel changes the widget is rebuilt. Not always a state change produces a viewmodel change. The `StoreConnector` widget is a typed widget and takes two types in its definition: the store's type (the `AppState`) and the viewmodel's type (in this case just a `TabState` object). The `HomePage` only needs the part of the state related to the tab and, for this reason, it is not necessary to create an ad hoc viewmodel. The model of the `TabState` defined in Source Code 2.2 is enough to contain the necessary part of the state for the `HomePage` creation. In the `converter` field a function is provided which manipulates the state returning the current `TabState` value. The `builder` field is populated with a function that returns the usual `Scaffold` widget. Inside this function, the current `context` and the object returned from the `converter` function can be used. This last one is used to populate the `Scaffold` widget as usual.

#### Source Code 2.62: Todo app - Redux - HomePage implementation

```

class HomePage extends StatefulWidget {
  final void Function() onInit; //new parameter

  const HomePage({Key? key, required this.onInit}) : super(key: key);
}

```



```

@override
State<HomePage> createState() => _HomePageState();
}

class _HomePageState extends State<HomePage> {
  @override
  void initState() {
    //using the new function parameter to start the fetching process
    widget.onInit();
    super.initState();
  }

  @override
  Widget build(BuildContext context) {
    print("Building HomePage");
    //use a StoreConnector widget to access the state
    return StoreConnector<AppState, TabState>(
      //scan the store to retrieve the current tab value
      converter: (store) => store.state.tabState,
      builder: (context, currTab) {
        return Scaffold(
          appBar: AppBar(
            title: const Text("Todo App"),
            actions: [
              currTab == TabState.todos //use it here
                ? const VisibilityFilterSelector()
                : Container()
            ],
          ), //use it here
          body: currTab == TabState.todos ? const
            TodoView() : const Stats(),
          bottomNavigationBar: const TabSelector(),
          floatingActionButton: currTab == TabState.todos //use it here
            ? FloatingActionButton(...)
            : Container());
      },
    );
  }
}

```

```
);
}
}
```

We can now start implementing the component widgets but, first, a short digression about Selectors is taken.

**Selectors** - They are introduced here [RIFERIMENTO](#) . Selectors are used to compute those parts of the state that entirely depends on other parts. In our case, for example, the filtered list entirely depends on the list of todos and the visibility filter. It is not included in the AppState with the idea of computing it in the presentation layer. This decision also comes from the fact that, if situated in the centralized state, would be hard to syncronize it with the changes in the todos list and in the visibility filter. The easiest way to deal with the filtered list is to compute it in the presentation layer before building the TodoView widget. However, this way of doing can become soon quite heavy by the fact that the computation of the filtered list is performed every time the widget is rebuilt. In this scenario Selectors come into play to memoize the previously computed values and to reuse them once accessed. Selectors are just functions that take as input the state and return an element composed using it. All the memorization part is performed by a third party package called *Reselect*. In order to use this package it must be included in the pubspec.yaml file under the *dependencies* field. It provides some functions called *createSelector* that take care of memoizing precomputed values and understanding when is necessary recompute them. Selectors can be simple or composed. For example, two simple selectors can be implemented in our case. One takes the state and returns the visibility filter and the other takes the state and returns the list of todos.

**Source Code 2.63:** Todo app - Redux - first level Selectors implementation

```
final todosSelector = (AppState state) => state.todos;

final filterSelector = (AppState state) => state.visibilityFilter;
```

Selectors can be composed with other selectors to create articulated objects. Selectors are composed using the *createSelector* function followed by a number. For example, a selector computing the list of completed todos can be built using the *todosSelector* and

the *createSelector1* function. The same can be done to compute the list of pending todos. Another Selector is created to finally compute the filtered list. It uses the four other selectors we just implemented and the *createSelector4* function. Besides of making the code more readable, selectors, allow to optimize the application's performances.

**Source Code 2.64:** Todo app - Redux - composed Selectors implementation

```
//compute the list of completed todos
final completedTodosSelector = createSelector1(
  todosSelector,
  (List<Todo> todos) =>
    todos.where((todo) => todo.completed == true).toList());

//compute the list of pending todos
final pendingTodosSelector = createSelector1(
  todosSelector,
  (List<Todo> todos) =>
    todos.where((todo) => todo.completed == false).toList());

//compute the filtered list
final filteredTodosSelector = createSelector4(
  todosSelector, filterSelector,
  completedTodosSelector, pendingTodosSelector,
  (List<Todo> todos, VisibilityFilter filter, List<Todo> completed,
    List<Todo> pending) {
  switch (filter) {
    case VisibilityFilter.completed:
      return completed;
    case VisibilityFilter.notCompleted:
      return pending;
    case VisibilityFilter.all:
      return todos;
  }
});
```

**The `TodoView` component** - After this short digression about selectors, we are ready to set up the `TodoView` component. Its internal `ListView` widget is wrapped into a `StoreConnector` widget typed with the `AppState` type and the `List<Todo>` type. The `TodoView` component just needs to access the part of the state concerning the filtered list of todos that is representable with an object of type `List<Todo>`. The list of filtered todos is not directly available in the `AppState` but selectors can be used to compute it. In the `converter` field of the `StoreConnector` widget, a function is provided which takes the store and returns the filtered list using the *filteredTodosSelector* defined Source Code 2.64. The `converter` function's output is available inside the `builder` field's function and is used to populate the `ListView` widget as usual.

**Source Code 2.65:** Todo app - Redux - `TodoView` component implementation

```
class TodoView extends StatelessWidget {
  const TodoView({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    //use the StoreConnector widget to access the state
    return StoreConnector<AppState, List<Todo> > (
      builder: (context, todos) {
        print("Building TodoView");
        return ListView.builder(
          itemCount: todos.length, //use it here
          itemBuilder: (context, index) {
            return TodoItem(
              todo: todos.elementAt(index), //use it here
            );
          },
        );
      },
      converter: (store) {
        //use the selector
        return filteredTodosSelector(store.state);
      });
  }
}
```

```
}
```

**The `TodoItem` component** - The `TodoItem` component does not require any modification with respect to the implementation proposed in Source Code 2.8. It just receives a `todo` from the parent widget and exposes it to the user. The only missing part is the `onChanged` field of the `Checkbox` widget which is still empty. Inside the `onChanged` field, a function must be provided which updates the `completed` field of the visualized `todo`. The store is accessed using the `of` method of the `StoreProvider` widget (the `of` method gets the nearest instance of provided type, in our case `AppState`). The store is then used to dispatch an action of type `SetCompletedTodoAction` created using the `id`, of the visualized `todo`, and the `completed` Boolean value provided by the `onChanged` function.

**Source Code 2.66:** Todo app - Redux - `TodoItem` component's `onChanged` field implementation

```
Checkbox(
  value: todo.completed,
  onChanged: (completed) {
    StoreProvider.of<AppState>(context).dispatch(
      SetCompletedTodoAction(todo.id, completed!));
  }),
```

**The `VisibilityFilterSelector` component** - The `VisibilityFilterSelector` component only accesses the part of the state concerning the filter. The entire `DropDownButton` widget is wrapped into a `StoreConnector` widget. The `StoreConnector`'s `converter` field is filled with a function taking the store and returning the current filter value. To do so, it uses the `filterSelector` selector implemented earlier in Source Code ???. The output of the `converter` function is accessed in the `builder` field function and used to populate the `DropDownButton` widget. The function used in the `onChanged` field of the `DropDownMenuItem` widgets gets an instance of the store using the `StoreProvider` widget's `of` method and dispatches an action of type `SetVisibilityFilterAction` using the `DropDownMenuItem`'s filter value.

**Source Code 2.67:** Todo app - Redux - VisibilityFilterSelector component implementation

```
@override
Widget build(BuildContext context) {
  //using a StoreConnector widget to access the state
  return StoreConnector<AppState, VisibilityFilter>(
    //scan the store to retrieve the filter value
    converter: (store) => filterSelector(store.state),
    builder: (context, activeFilter) {
      print("Building Visibility filter");

      return DropdownButton<VisibilityFilter>(
        value: activeFilter, //use it here
        items: (...),
        onChanged: (filter) {
          //dispatch an action of type SetVisibilityFilterAction
          StoreProvider.of<AppState>(context)
            .dispatch(SetVisibilityFilterAction(filter!));
        },
      );
    },
  );
}
```

**The TabSelector component** - Also in this case, the TabSelector component requires to read and also write the AppState. A StoreConnector widget is used to wrap the BottomNavigationBar widget and to connect it to the state. The view-model to be returned by the *converter* function is just an object of type TabState. An arrow function returning the current AppState's tab value is provided to the *converter* field. The function's output is then used in the *builder* field's function to populate the BottomNavigationBar widget. The *onTap* field of the BottomNavigationBar widget is filled with a function that dispatches an action of type *SetTabAction* when fired.

**Source Code 2.68:** Todo app - Redux - TabSelector component implementation

```

class TabSelector extends StatelessWidget {
  const TabSelector({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    //use a StoreConnector widget to access the state
    return StoreConnector<AppState, TabState>(
      //scan the store to retrieve the tab value
      converter: (store) => store.state.tabState,
      builder: (context, currTab) {
        print("Building Tab Selector");

        return BottomNavigationBar(
          //use it here
          currentIndex: TabState.values.indexOf(currTab),
          onTap: // dispatch an action of type SetTabAction
            (index) => StoreProvider.of<AppState>(context)
              .dispatch(SetTabAction(TabState.values.elementAt(index))),
          items: (...)
        );
      },
    );
  }
}

```

**The Stats component** - The stats component only requires to read the state. The Center widget is wrapped into a StoreConnector widget. In the *converter* field's function the *completedTodoSelector* defined in Source Code 2.64 selector is used to access the list of completed todos. In this case the viewmodel to be outputted is just an int value representing the number of completed todos.

**Source Code 2.69:** Todo app - Redux - Stats component implementation

```
class Stats extends StatelessWidget {
  const Stats({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    //use the StoreConnector widget to access the state
    return StoreConnector<AppState, int>(
      builder: (context, completed) {
        print("Building Stats");
        //use it here
        return Center(child: Text(completed.toString()));
      },
      converter: (store) {
        // use the selector
        return completedTodosSelector(store.state).length;
      },
    );
  }
}
```

At this point all the base functionalities have been implemented and are working fine.

## Features addition

The first thing to do is to make the state provide a way of adding and updating todos. For this purpose two new actions are created with the name *AddTodoAction* and *UpdateTodoAction* respectively. In the *AddTodoAction*, are contained the name and the description for the todo to be create. In the *UpdateTodoAction*, besides the new name and description, also the id of the todo to be modified is contained.

**Source Code 2.70:** Todo app - Redux - AddTodoAction and UpdateTodoAction implementation

```
class AddTodoAction {
  final String name;
  final String desc;
```



```
    AddTodoAction(this.name, this.desc);
}

class UpdateTodoAction{
    final String name;
    final String desc;
    final int id;

    UpdateTodoAction(this.name, this.desc, this.id);
}
```

In order to handle these new actions two new reducers are created. They are called respectively *addTodo* and *updateTodo*. The *addTodo* reducer creates a new todo using the information contained in the *AddTodoAction* instance and a newly generated unique id. Then, it creates a new list instance and populates it with the elements of the old list plus the new todo.

**Source Code 2.71:** Todo app - Redux - addTodo reducer implementation

```
List<Todo> _addTodo(List<Todo> todos, AddTodoAction action) {
    //generate new unique id
    int newId = generateId(todos);
    //create a new todo instance
    Todo newTodo = Todo(
        id: newId,
        name: action.name,
        description: action.desc + " " + newId.toString(),
        completed: false);

    return List.from(todos)..add(newTodo);
}
```

The *updateTodo* reducer modifies the todo with the id matching the one contained in the action. Then, it generates a new list and fills it with the element contained in the

current one.

**Source Code 2.72:** Todo app - Redux - updateTodo reducer implementation

```
List<Todo> _updateTodo(List<Todo> todos, UpdateTodoAction action){

  List<Todo> newList= todos.map((todo) => todo.id == action.id
    ? Todo(
      id: action.id,
      name: action.name,
      description: action.desc,
      completed: todo.completed)
    : todo).toList();

  return List.from(newList);
}
```

These new reducers are then combined with the already existing ones in the *combineReducers* function and linked with the corresponding action using the typed class *TypedReducer*.

**Source Code 2.73:** Todo app - Redux - adding addTodo reducer and updateTodo reducer to the todoReducer

```
final todoReducer = combineReducers<List<Todo>>([
  TypedReducer<List<Todo>, AddTodoAction>(_addTodo), //new reducer
  TypedReducer<List<Todo>, LoadTodoSucceededAction>(_setLoadedTodo),
  TypedReducer<List<Todo>, SetCompletedTodoAction>(_setCompletedTodo),
  TypedReducer<List<Todo>, UpdateTodoAction>(_updateTodo), //new reducer
]);
```

The AppState can now handle actions of type *AddTodoAction* and *UpdateTodoAction*. These new functionalities can now be used in the AddTodoPage and in the UpdateTodoPage. The StoreProvider widget has been positioned in the root of the

application to be available in all the subtrees. Is sufficient, though, to access the store in the `AddTodoPage` and dispatch an action of type *AddTodoAction*, when the `TextButton` widget is tapped.

**Source Code 2.74:** Todo app - Redux - `AddTodoPage` *onPressed* field implementation

```
TextButton(  
  onPressed: () {  
    //create a new action  
    final AddTodoAction action= AddTodoAction(textControllerName.text,  
      textControllerDesc.text);  
    //dispatch it  
    StoreProvider.of<AppState>(context).dispatch(action);  
    Navigator.pop(context);  
  },
```

The same is done in the `UpdateTodoPage`. Once the `TextButton` widget is tapped an action of type *UpdateTodoAction* is dispatched.

**Source Code 2.75:** Todo app - Redux - `UpdateTodoPage` *onPressed* field implementation

```
TextButton(  
  onPressed: () {  
    //create an action  
    final UpdateTodoAction action=  
      UpdateTodoAction(textControllerName.text,textControllerDesc.text,widget.todo  
    //dispatch it  
    StoreProvider.of<AppState>(context).dispatch(action);  
    Navigator.pop(context);  
  },  
  child: const Text("Confirm"))
```

All the features have been successfully added.

## Rendering optimization

In order to perform the rendering optimizations we will leverage on the fact that, the `StoreConnector` widget, only rebuilds when the viewmodel, it relies on, changes. Or better, this happens when a specific field of the `StoreConnector` widget, called *distinct*, is set to true. This feature, the `Redux` package provides, makes the optimization process really easy. We just need to define the correct viewmodel and provide it with the correct equality operator. Some changes must be done in the `TodoView` widget and in the `TodoItem` widget. Firstly, the `TodoItem` widget needs to interact with the state in order to understand when a change regarding its todo is performed. For the moment, indeed, the `TodoItem` widget just receives a todo instance from the parent widget and exposes it to the user. A `StoreConnector` widget is used to read the state in the `TodoItem` widget. The complete instance of the todo to be visualized is not necessary anymore but the id only is enough. Using the id, the corresponding todo is searched in the store by the *converter* field's function and passed to the *builder* field. The widget returned by the *builder* function remains the same with the only exception that it uses the todo instance got from the store instead of the one passed by the parent widget.

**Source Code 2.76:** Todo app - Redux - accessing the state into `TodoItem` component

```
class TodoItem extends StatelessWidget {
  final int id; //todo variable substituted with a int one

  const TodoItem({Key? key, required this.id})
    : super(key: key);

  @override
  Widget build(BuildContext context) {
    //use a StoreConnector widget to access the state
    return StoreConnector<AppState, Todo>(
      //set the distinct value to true enabling
      //comparison between viewmodels
      distinct: true,
      converter: (store) =>
        //retrive the corresponding todo scanning the store
        store.state.todos.firstWhere((element) => element.id == id),
```

```
builder: (context, todo) {  
  print("building: Todo Item \${id}");  
  //the remaining part remains the same  
  return InkWell(. . .);  
});  
}  
}
```

Now that the `TodoItem` widget listens for its own `todo` changes, the optimization process concerning the `TodoItem` widget is automatically performed. We said, indeed, that the `StoreConnector` widget is rebuilt every time its `viewmodel` changes and we set the `viewmodel` as the corresponding `todo` instance in the `AppStore`. Once a state change occurs, the `StoreConnector` widget compares the current `todo` with the new one and, in case they differ, it rebuilds. To notice that this mechanism works because we redefined the equality operator between objects of type `Todo` in Source Code 2.4. An object of type `Todo` is equal to another one if all their internal values match. This equality differs from the traditional one by the fact that does not check for the entity's equality. Indeed, if it would, the two `todos` would appear to be different everytime even if their internal values match. This because, once a new state is emitted, the list of `todos` is recreated from scratch and its internal `todos` are replaced with new instances. In the dart language two different objects end to be different also if their internal values are exactly the same. This way of handling object already showed up numerous times in this overview and will show up even more in the next implementations. Going back to the `TodoItem` component, it already uses the correct equality operator to compare different `viewmodels` and so is capable to understand when to rebuild autonomously. The same process must be done in the `TodoView` widget. It already uses a `StoreConnector` widget to derive the list of filtered `todos` from the store. However, as we just said, two different plain lists appear to be always different by default also if their internal aspects matches, leading to unconditioned rebuilds. Moreover, it is not possible to redefine the equality operator for lists and, also if it would, it would not be a good idea. A simple way to handle this scenario is to create an ad hoc `viewmodel` and redefine its equality operator in order to match our own rebuilding logic. To do so, a local class is created and called `ViewModel`. This local class just contains a list of `todos`.

**Source Code 2.77:** Todo app - Redux - `TodoView` component ad hoc `ViewModel` implementation

```
class _ViewModel {  
    final List<Todo> todos;  
  
    _ViewModel({required this.todos});  
  
}
```

Inside the `ViewModel` class the equality operator is overridden making two `ViewModel` instances equal when their length matches and their internal ids match too. In this way the `TodoView` widget is rebuild only in case the filtered todos list has reported a structural change. (structural and not structural changes are explained in paragraph 2.1.3).

**Source Code 2.78:** Todo app - Redux - `ViewModel`'s equality operator override

```
//redefine the == operator to detect structural changes  
@override  
bool operator ==(Object other) {  
    return ((other is _ViewModel) &&  
        todos.length == other.todos.length &&  
        todos.every(  
            (todo) => other.todos.any((element) =>  
                todo.id == element.id)));  
}  
  
@override  
// TODO: implement hashCode  
int get hashCode => todos.hashCode;
```

After setting the *distinct* field to true and modifying the *converter* function to return a `ViewModel` instead of a plain `List` the optimizations are basically done.

**Source Code 2.79:** Todo app - Redux - `TodoView` component renders optimization

```

class TodoView extends StatelessWidget {
  const TodoView({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    return StoreConnector<AppState, _ViewModel>(
      distinct: true, //set the distinct field to true
      builder: (context, vm) {
        print("Building TodoView");
        return ListView.builder(
          itemCount: vm.todos.length, //use the viewmodel
          itemBuilder: (context, index) {
            return TodoItem(
              id: vm.todos.elementAt(index).id, //use the viewmodel
            );
          },
        );
      },
      converter: (store) { //return a ViewModel instead of a plain list
        return _ViewModel(todos: filteredTodosSelector(store.state));
      });
  }
}

```

To put the icing on the cake we set the *distinct* field to true also in the *VisibilityFilterSelector* component and in the *TabSelector* component. In this way they are rebuilt only in case their prospective of the state changes and not at every state transition.

## Conclusions

Table 2.2 reports some measurements taken from the *InheritedWidget*'s implementation process. The *lines of code* column represents the lines of code added or updated with respect to the shared project structure proposed in subsection 2.2.1. The *time* column represents the time spent in order to implement the corresponding subprocess. The unit of measure **h** stands for hours and **m** stands for minutes. The *lines-time ratio* column

represents the average number of lines written in a minute. The *classes* column represents the number of created classes in each subprocess.

### Recap

	lines of code	time	lines/time ratio	+classes
<b>base functionalities</b>	156	9-11 h	0.26 l/m	6
<b>feature addition</b>	50	15-20 m	2.94 l/m	2
<b>rendering optimization</b>	28	1 h	0.46 l/m	1

Table 2.2: Redux measurement table

Figure 2.10 represents a pie chart showing the percentage of lines of code written in each implementation's process, including the one regarding the shared structure. The whole process is quite balanced in term of lines of code.

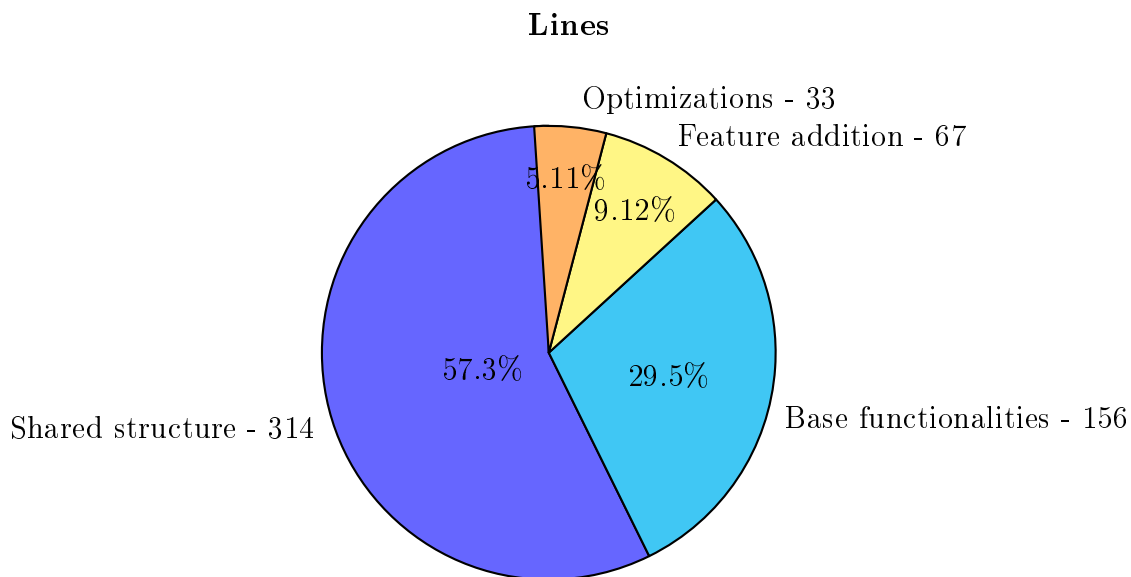


Figure 2.10: Shows the pie chart regarding the lines of code spent in each subprocess for the Redux implementation

Figure 2.11 represents a pie chart showing the percentage of time spent in each implementation's process. Notice that the learning process and the implementation of the base functionalities took more than the 85% of the entire time.



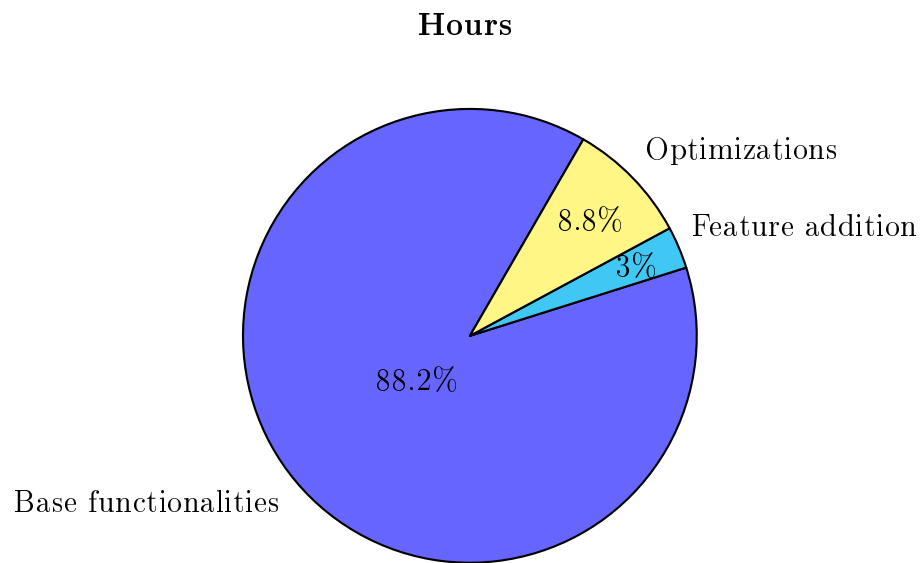


Figure 2.11: Shows the pie chart regarding the hours spent in each subprocess for the Redux implementation

Figure 2.12 shows the final folders structure for the InheritedWidget implementation. The only file added to the original folders structure is the `todo_provider.dart` file.

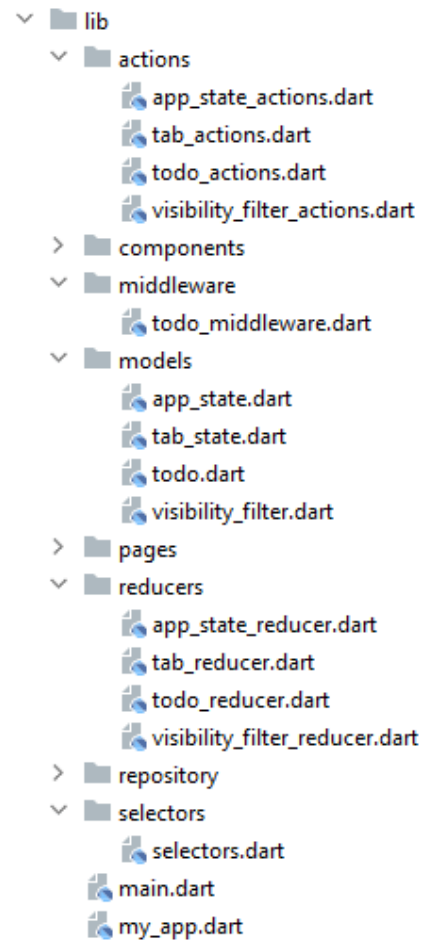


Figure 2.12: Shows the final folders structure for the Redux implementation of the Todos app

Figure ?? represents the widget's tree structure for the Redux final application. Notice the `StoreProvider` widget, situated above the `HomePage`, providing an instance of the store to the subtree. Also notice all the `StoreConnector` widgets accessing the state using their corresponding viewmodel.

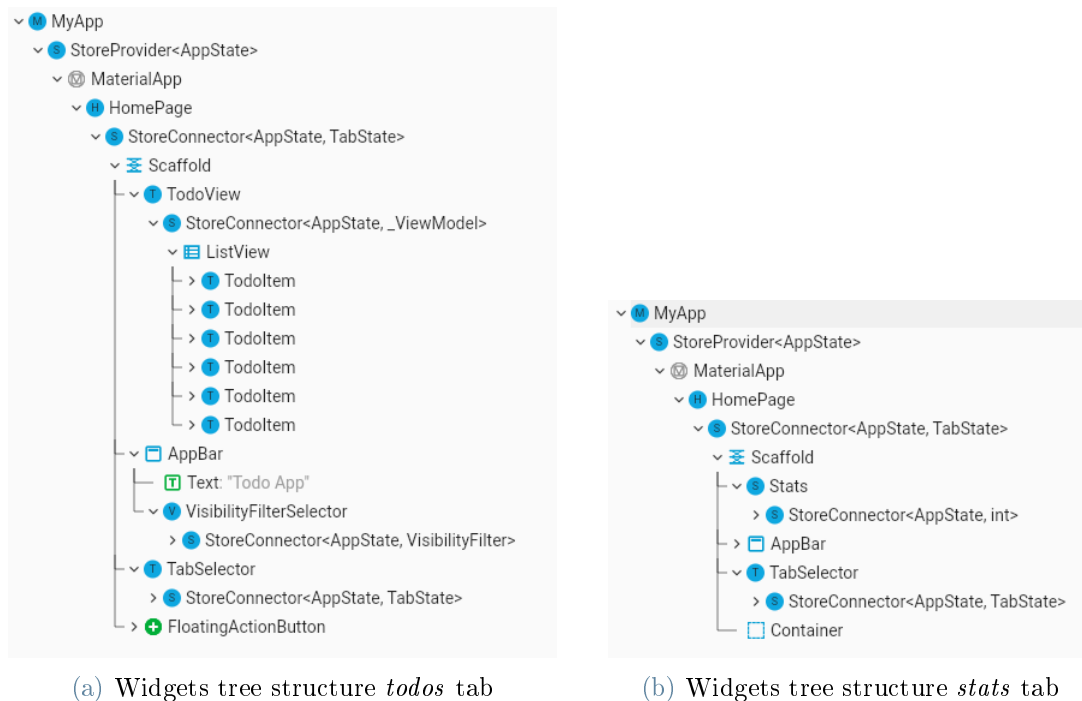


Figure 2.13: Shows the widgets tree structure for Redux implementation of the Todos app

## 2.2.4. BloC implementation

In this section the state management solution called Bloc is used to implemented the todo application.

### Base funtionalities

**States** - The application state is decomposed in four smaller states: the state of the list of todos, the state of the filtered list of todos and the filter, the state of the statistics and the state of the tab. The state of the list of todos contains the whole list of todos. The state of the filtered list of todos and of the filter contains a filter ,of type VisibilityFilter ,and a list of todos matching the filter value. The state of the stats contains an int number indicating the number of completed todos. Lastly, the state of the tab contains the value of the HomePage's active tab. The state of the list of todos and the state of the tab are independent. The state of the filter and the state of the stats , instead, are directly linked to the state of the list of todos. They will , indeed, react to the changes in the state of the list of todos and update consequently.

**The states of the list of todos** - First of all we start defining and naming the possible states of the list of todos. These states are only two: `TodosLoadingState` and `TodosLoadedState`. The Loading state indicates that the list of todos is still loading. The loaded state, instead, indicates that the list of todos has been successfully fetched from the database and is available. In order to define these two states a new abstract class is created. It is called `TodosState`. It must extend the class `Equatable`. The `Equatable` class is useful to define equality between states without the need to override the equality operator in every state class. The `TodosLoadingState` does not contain any other information. The `TodosLoadedState` contains, instead, a list filled with todos.

**Source Code 2.80:** Todo app – Bloc - states definition for the list of todos

```
abstract class TodosState extends Equatable{
  const TodosState();

  @override
  List<Object> get props => [];
}

class TodosLoadingState extends TodosState{

  @override
  String toString() => 'TodosState - TodosLoadingState';
}

class TodosLoadedState extends TodosState{
  final List<Todo> todos;
  const TodosLoadedState(this.todos);

  @override
  List<Object> get props => [todos];

  @override
  String toString() => 'TodosState - TodosLoadedState';
}
```

**The state of the filtered list and the filter** - Also in this case there are only two possible states: `FilteredTodosLoadingState` and `FilteredTodosLoadedState`. The loading state identifies the fact that the filtered list hasn't been computed (or todos fetched) yet. The Loaded state, instead, identifies the fact that the list of todos has been successfully fetched and the list of filtered todos computed. It contains two variables: a `VisibilityFilter` and a `List` of todos. An abstract class, called `FilteredTodosState`, must be created and extended with `Equatable` class. All the others state classes, belonging to the state relative to the filtered list and the filter, will extend the `FilteredTodosState` abstract class. Someone can notice that, the state of the filtered list and the filter, contains two different aspects of the application state: the filter and the filtered list precisely. In this case it is possible to further split the state and create two separated blocs, handling respectively the filter and the filtered list. From a general point of view, the state should be divided in the more possible pieces to keep things well separated and clean, like we do for classes and methods. However, the bloc pattern do not specify how granular should be the state fragmentation and, theoretically, we could decide to use a single bloc to handle the whole application's state, like in `Redux`. In this particular case, I decided to implement a trade off and keep the filter and the filtered list in the same bloc. They concern, indeed, two similar aspects of the data and, splitting them, would require the bloc of the filtered todos to depend on the bloc of the filter also, making its dependencies going from one bloc to two blocs (the bloc of the todos and the bloc of the filter).

**Source Code 2.81:** Todo app - Bloc - states definition for the filtered list of todos and the filter

```
abstract class FilteredTodoState extends Equatable {
  const FilteredTodoState();

  @override
  List<Object> get props => [];
}

class FilteredTodoLoadingState extends FilteredTodoState {
  @override
  String toString() => 'FilteredTodoState - FilteredTodoLoadingState';
}
```

```

class FilteredTodoLoadedState extends FilteredTodoState {
  final List<Todo> todos;
  final VisibilityFilter filter;

  const FilteredTodoLoadedState(this.todos, this.filter);

  @override
  List<Object> get props => [todos, filter];

  @override
  String toString() => 'FilteredTodoState - FilteredTodoLoadedState';
}

```

**The state of the stats** - Also in this case there only two possible states: `StatsLoadingState` and `StatsLoadedState`. The first identifies the fact that stats hasn't been computed yet and do not contains any additional information . The second identifies the fact that stats are available and contains an int variable inside , *completed* that represents the actual stats.

**Source Code 2.82:** Todo app - Bloc - states definition for the stats

```

abstract class StatsState extends Equatable {
  const StatsState();

  @override
  List<Object> get props => [];
}

class StatsLoadingState extends StatsState {

  @override
  String toString() {
    return 'StatsState - StatsLoadingState';
  }
}

```

```

}

class StatsLoadedState extends StatsState {
    final int completed;

    const StatsLoadedState(this.completed);

    @override
    List<Object> get props => [completed];

    @override
    String toString() {
        return 'StatsState - StatsLoadedState : {completed: \${completed}}';
    }
}

```

**The state of the tab** - In order to define the states of the tab ,the enumeration presented Source Code 2.2 is enough.

**Events** - Now that states for every possible part of the application have been defined, it's the turn of Events. Events are just classes. They can represent a specific actions the user can perform or also internal changes. They enable the states to mutate creating transitions.

**Events of the list of todos** - For the moment is sufficient to define two events only. One identifies the action of fetching todos from the database and is called LoadTodosEvent. It do not contains any other information. The other identifies the action of changing the *completed* field of a specific todo and is called SetCompletedTodoEvent. It contains two informations, the *id* of the specific todo to be modified and the new value for the *completed* field. Also in this case, a new abstract class is defined and extended with Equatable class. It is called TodosEvent. All other event classes , concerning the state of the list of todo ,are extended with this abstract class.

**Source Code 2.83:** Todo app - Bloc - events definition for the list of todos

```

abstract class TodosEvent extends Equatable {
  const TodosEvent();

  @override
  List<Object> get props => [];
}

class LoadTodosEvent extends TodosEvent {
  @override
  String toString() => 'TodosEvent - LoadTodosEvent';
}

class SetCompletedTodoEvent extends TodosEvent {
  final int id;
  final bool completed;

  const SetCompletedTodoEvent(this.id, this.completed);

  @override
  String toString() => 'TodosEvent - SetCompletedTodoEvent';
}

```

**Events for the filtered list and the filter** - Two events are enough to define all possible transition for the state of the filtered list and the filter. One is called `FilteredTodoChangeFilterEvent` and is used to change the state of the filter. It contains , indeed, a `VisibilityFilter` variable that indicates the new value for the filter. The other event is called `TodosUpdatedEvent` . It informs the part of the state concerning the filtered list that the list of todo has changed. A new filtered list must be computed ,tough, and a new `FilteredTodosLoadedState` emitted. It contains internally a variable providing the changed list of todos.

Also in this case ,all event classes extend a shared abstract class called `FilteredTodoEvent` which , in turn, extends the `Equatable` class.

**Source Code 2.84:** Todo app - Bloc - events definition for the filtered list of todos and the filter



```
abstract class FilteredTodoEvent extends Equatable {
    const FilteredTodoEvent();

    @override
    List<Object> get props => [];
}

class FilteredTodoChangeFilterEvent extends FilteredTodoEvent {
    final VisibilityFilter filter;

    const FilteredTodoChangeFilterEvent(this.filter);

    @override
    List<Object> get props => [filter];

    @override
    String toString() => 'FilteredTodoEvent - '
        'FilteredTodoChangeFilterEvent {filter: \${filter}}';
}

class TodoUpdatedEvent extends FilteredTodoEvent {
    final List<Todo> todos;

    @override
    List<Object> get props => [todos];

    const TodoUpdatedEvent(this.todos);

    @override
    String toString() => 'FilteredTodoEvent - TodoUpdatedEvent';
}
```

**Events for the stat's and tab's state** - Both the state of the tab and the state of the stats require just one event. The event concerning the state of the tab is called

ChangeTabEvent and contains internally a variable of type TabState indicating the value of the new tab. The event concerning the state of the stats is called StatsUpdatedEvent and is generated after the fetching or the updating of the list of todos in the TodoBloc. Precisely it is generated once a new state of type TodosLoadedState is emitted in the TodoBloc. It contains internally the new list of todos of the emitted state. Also in this case, both the event for the stats and the event for the tab extends respectively the abstract classes TabEvent and StatsEvent.

**Source Code 2.85:** Todo app - Bloc - events definition for the stats and the tab

```
abstract class StatsEvent extends Equatable{
    const StatsEvent();
}

class StatsUpdatedEvent extends StatsEvent{

    final List<Todo> todos;
    const StatsUpdatedEvent(this.todos);

    @override
    List<Object> get props => [todos];

    @override
    String toString() => 'StatsEvent - StatsUpdatedEvent';
}

abstract class TabEvent extends Equatable{

    const TabEvent();

}

class ChangeTabEvent extends TabEvent{
    final TabState tab;

    const ChangeTabEvent(this.tab);
}
```

```

@override
List<Object> get props => [tab];

@override
String toString() => 'TabUpdated { tab: \ $tab }';
}

```

**The Blocs** - At this point ,both the events and the states necessary to implement di base functionalities of the application have been defined. Is possible ,then, to implement the classes, called *blocs*, that are going to define the way in which new states are emitted in relation to the received events.

**The bloc for the list of todos** - To define the bloc for the list of todos is necessary to create a new class, we name `TodoBloc`, and make it extends the `Bloc` class, provided by the `flutter_bloc` package. Moreover, it is necessary to provide , in the extension, also the type of events and states the bloc will manage. In our case , the `ToboBloc` class handles events of type `TodosEvent` and states of type `TodosState`, previously defined. A constructor must be defined where the bloc is initialized with a initial state. The initial state for the `TodoBloc` is of type `TodoLoadingState` by the fact that, at the application start, todos are still to be fetched from the database. The `Bloc` class ,provided by the solution ,requires to override the `mapEventToState` method . The `mapEventToState` method is ,indeed, annotated with the `@override` notation meaning that the implementation we are giving substitutes the one of the `Bloc` class. The override is mandatory. The method `mapEventToState` takes as argument an event of type `TodosEvent` and returns a `Stream` of `TodosStates`. It is asynchronous ( indicated by the `async*` annotation after the arguments) and do not terminate during the entire execution of the application. It keeps listening for new events, tough. Inside its implementation , a series of nested *if-else* statement have the task of identifying the type of the received event and to emit the consequent state. Indeed, the received event is always of the abstract type `TodosEvent` but can be of the subtype `LoadTodosEvent` or `SetCompletedTodoEvent`. Once the subtype is defined ,the event logic is processed and the new state emitted. The syntax *yield\** Is used , instead of the classic syntax *return*,because it allows to emit a new state, in the `Stream` , without terminating di `mapEventToState` method execution. If the *return* syntax is used , indeed, the new state is emitted correctly but the method

terminates and the application become unresponsive. For code readability, the logic to be executed when a `LoadTodoEvent` or a `SetCompletedTodoEvent` is received has been moved to two other private methods ,called respectively *mapLoadTodoToState* and *mapSetCompletedToState*. This kind of practice is used also in the subsequence blocs implementation. The *mapLoadTodoToState* method takes as single argument an event of type `LoadTodosEvent` ( not a generic `TodosEvent` anymore) and bothers to fetch the todos from the database using the `TodoRepository` class. In case it successfully gets the list of todos, it emits a new state of type `LoadedTodoState` containing it. In case of failure ,instead, the `TodosLoadingState` is emitted. The *mapSetCompletedToState* method takes as single argument an event of type `SetCompletedTodoEvent`. After checking that the current state is of type `TodosLoadedState` ( in case it is not is meaningless to update the todo not having an actual list) a new list of todo is created containing the same todos as before except for the one with the id matching the value contained in the event. That todo, indeed, is replaced with a new one with the *completed* field set to the completed value contained in the event. Notice that a new instance of the list must be created and provided to the new state. If we just mutate the list present in the previous state the `Equatable` class do not identify any difference between the previous state and the new emitted one, and consequently, do not notify any listener.

#### Source Code 2.86: Todo app - Bloc - `TodoBloc` implementation

```
class TodoBloc extends Bloc<TodosEvent, TodosState> {
  //initialize the bloc's state at creation
  TodoBloc() : super(TodosLoadingState());

  @override
  Stream<TodosState> mapEventToState(TodosEvent event) async* {
    // if an event of type LoadTodosEvent is receiver
    if (event is LoadTodosEvent) {
      yield* _mapLoadTodosToState(event);
    }
    // if an event of type SetCompletedTodoEvent is received
    } else if (event is SetCompletedTodoEvent) {
      yield* _mapSetCompletedToState(event);
    }
  }
}
```

```

Stream<TodosState> _mapLoadTodosToState(LoadTodosEvent event) async* {
  try {
    //fetch todos
    final List<Todo> todos = await TodoRepository.loadTodos();
    yield TodosLoadedState(todos);
  } catch (e) {
    yield TodoLoadingState();
  }
}

Stream<TodosState> _mapSetCompletedToState(
  SetCompletedTodoEvent event) async* {
  if (state is TodosLoadedState) {// create a new updated list
    List<Todo> newList = (state as TodosLoadedState)
      .todos
      .map((todo) => todo.id == event.id
        ? Todo(
            name: todo.name,
            description: todo.description,
            id: todo.id,
            completed: event.completed)
          : todo)
      .toList();
    yield TodosLoadedState(newList);
  }
}

```

**The bloc for the filtered list and the filter** - The procedure is the same utilized for the todo bloc. A new class ,called `FilteredTodosBloc` ,is created and extended with the `Bloc` class. This new class handles the events of type `FilteredTodosEvent` and the states of type `FilteredTodosState`. Being the bloc of the filtered list of todos dependent from the bloc of the list of todos, an instance of this second one is passed inside the constructor at the initialization and used to listen for changes. The instance of the bloc of the todos is saved in a local variable of type `TodoBloc`. In this case the constructor is a bit more articulated with respect to the `TodoBloc`'s one. It emits the initial state

based on the state of `TodoBloc`. If the state is of type `loaded`, the constructor computes `filteredTodos`, and then emits `FilteredTodosLoadedState` using a filter of type `all`. If the state is of type `loading`, the constructor emits a state of type `FilteredLoadingState`.

**Source Code 2.87:** Todo app - Bloc - FilteredTodoBloc initialization

```
class FilteredTodoBloc extends Bloc<FilteredTodoEvent, FilteredTodoState> {
  //this variable is used to listen for changes in the todoBloc
  final TodoBloc todoBloc;

  FilteredTodoBloc({required this.todoBloc})
    : super(
      //initialize the state based on the todoBloc's state
      todoBloc.state is TodosLoadedState
        ? FilteredTodoLoadedState(
            (todoBloc.state as TodosLoadedState).todos,
            VisibilityFilter.all,
          )
        : FilteredTodoLoadingState(),
    )
}
```

In addition, the constructor must register the bloc to the changes in the `TodoBloc`. To do so, a particular variable of the `TodoBloc` instance, called *stream*, is used. The variable *stream* is present because the `TodoBloc` extends the `Bloc` class. It is, indeed, the variable where the *mapEventToState* method emits new states. We can register to its output using the method *listen*. Inside the *listen* method's call, a function must be provided. This function is called everytime the stream emits a new state. Inside this function the new emitted state can be accessed and used to implement some logic. Actually, we won't implement the logic there, instead, we emit a new event that will be handled by the *mapEventToState* method, defined later. Once a new state is emitted in the `TodoBloc` the function checks if the state is of type `TodosLoadedState`. In case it is, it means that a new list of todos is available. It can be the case that the list of todos has been just fetched or some todos have been updated. In both cases, the bloc of the filtered list must compute a new filtered list and emit a new state containing it. A specific event, called `TodoUpdatedEvent`, has been defined for this situation in Source

Code 2.84 where the events related to the bloc of the filtered list have been implemented.

**Source Code 2.88:** Todo app - Bloc - FilteredTodoBloc subscription to TodoBloc stream

```
class FilteredTodoBloc extends Bloc<FilteredTodoEvent, FilteredTodoState> {
  final TodoBloc todoBloc;
  //the todoSubscription variable is marked as late
  // because it is initialized after the constructor's execution
  late StreamSubscription todoSubscription;

  FilteredTodoBloc({required this.todoBloc})
    : super(
        todoBloc.state is TodosLoadedState
        ? FilteredTodoLoadedState(
            (todoBloc.state as TodosLoadedState).todos,
            VisibilityFilter.all,
        )
        : FilteredTodoLoadingState(),
    ) {
    //subscription to the todoBloc's state changes
    todoSubscription = todoBloc.stream.listen((state) {
      //in case a new state of type Loaded is emitted
      if (state is TodosLoadedState) {
        //an internal event of type TodoUpdatedEvent is emitted
        add(TodoUpdatedEvent((todoBloc.state as TodosLoadedState).todos));
      }
    });
  }
}
```

The *mapEventToState* method is overridden now defining the logic used to emit new state based on the received event. Like in the *TodoBloc*, also in this case, the method is asynchronous and returns a stream of *FilteredTodosStates*. The method takes as argument a single event of the generic abstract type *FilteredTodosEvent*. Inside the method, two nested *if-else* statement defines the type of the received event. The event can be of type *FilteredTodosChangeFilterEvent* or *TodosUpdatedEvent*. In the first case the private method *mapTodoChangeFilterEventToState* is called. In the second case the

private method *mapTodosUpdatedEventToState* is called.

**Source Code 2.89:** Todo app - Bloc - FilteredTodoBloc *mapEventToState* method override

```
@override
Stream<FilteredTodoState> mapEventToState(FilteredException event) async* {
  if (event is FilteredTodoChangeFilterEvent) {
    yield* _mapTodoChangeFilterEventToState(event);
  } else if (event is TodoUpdatedEvent) {
    yield* _mapTodoUpdatedEventToState(event);
  }
}
```

The *mapTodoChangeFilterEventToState* method checks that the state of the TodoBloc is of type TodosLoadedState ( in case it is not changing the filter is useless) and ,then ,it emits a new state of type FilteredTodosLoadedState containing the new filter and the new computed list of filtered todos.

**Source Code 2.90:** Todo app - Bloc - FilteredTodoBloc *\_mapTodoChangeFilterEventToState* method implementation

```
Stream<FilteredTodoState> _mapTodoChangeFilterEventToState(
  FilteredTodoChangeFilterEvent event) async* {
  if (todoBloc.state is TodosLoadedState) {
    yield FilteredTodoLoadedState(
      filterTodos((todoBloc.state as TodosLoadedState).todos,
        event.filter),
      event.filter);
  }
}
```

The method *mapTodoUpdatedEventToState* checks that the TodoBloc's state is of type TodosLoadedState and then emits a new state of type FilteredTodosLoadedState. The



emitted state uses and contains the current filter ,if it is set, otherwise used the filter of type *all*.

**Source Code 2.91:** Todo app - Bloc - FilteredTodoBloc *\_mapTodoUpdatedEventToState* method implementation

```
Stream<FilteredTodoState> _mapTodoUpdatedEventToState(
  TodoUpdatedEvent event) async* {
  // populate a filter value bases on the todoBloc's state
  final filter = (state is FilteredTodoLoadedState)
    ? (state as FilteredTodoLoadedState).filter
    : VisibilityFilter.all;
  if (todoBloc.state is TodosLoadedState) {
    yield FilteredTodoLoadedState(
      filterTodos((todoBloc.state as TodosLoadedState).todos, filter),
      filter);
  }
}
```

The last thing to do is to ensure that the subscription to the todoBloc is disposed when the current bloc terminates.

**Source Code 2.92:** Todo app - Bloc - FilteredTodoBloc *close* method implementation

```
@override
Future<void> close() {
  // cancel the subscription
  todoSubscription.cancel();
  return super.close();
}
```

**The bloc for the stats -** This bloc is similar to the previous one , it has to deal with one event only, tough : the StatsUpdatedEvent. As usual, the class StatsBloc is

defined an extended with the Bloc class. The StatsBloc class handles events of the type StatEvent and states of the type StatsState. Also in this case, the bloc depends on the bloc of the list of todo. For this reason, a variable of type TodoBloc is added and required in the constructor. In the constructor, a new initial state of type StatsLoadeingState is emitted. The subscription to the state's stream of the TodoBloc is perfomed passing a function ,called *onTodosStateChanged*, that check if the TodoBloc's state is of type TodoLoadedState and , in case it is ,emits a event of type StatsUpdatedEvent. This event will be handled by the *mapEventToState* method implemented later. The function *onTodosStateChanged* is called also once in the constructor to update the stats in case the TodoBloc is already of type TodosLoadedState on StatsBloc's creation.

**Source Code 2.93:** Todo app - Bloc - StatsBloc constructor implementation

```
class StatsBloc extends Bloc<StatsEvent, StatsState> {
  final TodoBloc todoBloc;
  //marked as late because it initialized after constructor exectuion
  late StreamSubscription todoSubscription;

  StatsBloc({required this.todoBloc}) : super(StatsLoadingState()) {
    // wrap the code into a function to reuse it
    void onTodosStateChanged(state) {
      if (state is TodosLoadedState) {
        add(StatsUpdatedEvent(state.todos));
      }
    }

    onTodosStateChanged(todoBloc.state);
    // if a new event is emitted in the todoBloc
    // execute the onTodosStateChanged function
    todoSubscription = todoBloc.stream.listen(onTodosStateChanged);
  }
}
```

The *mapEventToState* method requires a single *if-else* statement because the only event it has to handle is the StatsUpdatedEvent. When received, the list of todos it contains is used to compute the stats and ,then, a new StatsLoadedState is emitted. In the *close*

method the subscription to the TodoBloc is terminated.

**Source Code 2.94:** Todo app - Bloc - StatsBloc *mapEventToState* and *close* methods implementation

```
@override
Stream<StatsState> mapEventToState(StatsEvent event) async* {
  if (event is StatsUpdatedEvent) {
    final numCompleted =
      event.todos.where((todo) => todo.completed).toList().length;
    yield StatsLoadedState(numCompleted);
  }
}

@override
Future<void> close() {
  //cancel the subscription
  todoSubscription.cancel();
  return super.close();
}
}
```

**The bloc for the tab -** The procedure is the same as before. This time the bloc is really simple. After creating the class TabBloc and extending it to the Bloc class, the states and events to be handled are specified. In the constructor, the initial state is initialized and set to the TabState.todos value. The *mapEventToState* method is overridden connecting the only event with the emission of a state corresponding to the event's TabState internal value.

**Source Code 2.95:** Todo app - Bloc - TabBloc implementation

```
class TabBloc extends Bloc<TabEvent, TabState>{
  TabBloc() : super(TabState.todos);

  @override
  Stream<TabState> mapEventToState(TabEvent event) async*{
    if(event is ChangeTabEvent){
      yield event.tab;
    }
  }
}
```

**Observe blocs** - Terminates here the definition of the application's state. All states, events and blocs have been defined. It is possible to start testing the logic of the application, in the main function for example, initializing an object of type `TodoBloc` and trying to emit new events using the *add* method offered by the `Bloc` package.

**Source Code 2.96:** Todo app - Bloc - example of `TodoBloc` usage

```
void main() {
  //create a new bloc
  TodoBloc todoBloc= TodoBloc();
  //dispatch an event
  todoBloc.add(LoadTodosEvent());
}
```

The fact that it is possible to test the logic of the application without the need of writing a single widget explains how powerful the bloc package is. It is, indeed, really easy to split the logic layer from the presentation layer without dealing with complicated external dependencies. Moreover, it is possible to use an additional tool that helps the debugging and testing process; the `BlocObserver`. This component allows to intercept events, transitions and errors during the usage of the blocs and to execute arbitrary code when they occur. To use this component is necessary to define another class, that we call `AppBlocObserver`, and extend it with the `BlocObserver` class from the `Bloc`

package. Inside the `AppBlocObserver` class, it is possible to override three methods: `onEvent`, `onTransition` and `onError`. `onEvent` is called everytime a new event is emitted in a bloc and provides, in its implementation, the emitted event and the interested bloc. `onTransition` is called everytime a state transition occurs, inside a bloc. It offers two elements inside its implementation: the corresponding bloc and an object of type `Transition`. An object of type `Transition` is composed by two states and one event. The states are the ones preceding and postponing the event's execution. (note: not always the emission of an event produces a state transition. Some events may not generate a new state or may be ignored). Lastly, the method `onError` is called when an unexpected behaviour occurs and provides, in its implementation, the corresponding bloc where the error occurred and an object of type `StackTrace` that reports the stack situation when the error occurred. In our case the corresponding event, transition and error are displayed only but other, more articulated, implementation can be provided.

**Source Code 2.97:** Todo app - Bloc - `AppBlocObserver` implementation

```
class AppBlocObserver extends BlocObserver{
  @override
  void onEvent(Bloc bloc, Object? event) {
    super.onEvent(bloc, event);
    print("Event : " +event.toString());
  }

  @override
  void onTransition(Bloc bloc, Transition transition) {
    super.onTransition(bloc, transition);
    print( transition.toString());
  }

  @override
  void onError(BlocBase bloc, Object error, StackTrace stackTrace) {
    print(error);
    super.onError(bloc, error, stackTrace);
  }
}
```

Before running the application with the `runApp` method, the `AppBlocObserver`, we just

created , is set as the default observer for the blocs.

**Source Code 2.98:** Todo app - Bloc - setting the application's observer

```
void main() async {  
  Bloc.observer = AppBlocObserver();  
}
```

**Making the state accessible** - Similarly to the implementation with Redux and InheritedWidget , also in this case, a particular widget called BlocProvider must be used to make the state , or part of it, accessible in the subtree. Since the information regarding the list of todos needs to be accessible by the entire application its BlocProvider is situated in the root. In the *main* function , the first widget to be passed to the *runApp* method is indeed a BlocProvider widget. A BlocProvider widget is a typed widget , meaning that, the type of the bloc it makes accessible ,must be provided. In our case it needs to provide a bloc of type *TodoBloc*. Inside the BlocProvider widget , two fields must be filled: *create* and *child*. In the *create* field, a function taking as single argument the context and returning a bloc of the previously specified type ,must be provided. This function is executed on the BlocProvider initialization. However, the initialization of the BlocProviders is lazy. This means that it is performed when the BlocProvider is accessed the first time and not when it is inserted in the widget tree. This type of procedure is used to postpone heavy methods execution as lately as possible to avoid, in case they are never accessed, to perform useless computation and waste time. It is possible to set the lazy flag to false in case of the *create* function needs to be run instantly after the widget build. A function that instantiates a *TodoBloc* and emits the first event of the application, the *LoadTodoEvent*, is provided in the *create* field. In order to emit new events the method *add*, provided by the extension to Bloc class, is used. Moreover , the *cascade* notation ,offered by Dart language , is used to increase de readability of the code. It allows to concatenate more actions using the “..” notation. The *child* field is populated with the *MyApp* widget as usual.

**Source Code 2.99:** Todo app - Bloc - make the *TodoBloc* accessible using a BlocProvider widget

```

void main() async {
  //set the observer
  Bloc.observer = AppBlocObserver();
  //run di application and fetch todos
  runApp( BlocProvider<TodoBloc>(create: (context)=>
    TodoBloc()..add(LoadTodosEvent()),child: const MyApp()));
}

```

Beyond the `TodoBloc`, also the other blocs previously defined need to be made accessible. They are required in the `HomePage` only because the information they provide is not used by the other pages. This time a `MultiBlocProvider` is used to wrap the `HomePage`. A `MultiBlocProvider` is nothing else than a widget itself that contains a field called *providers* where a list of `BlocProvider` widgets is inserted. It is the same as nesting a series of `BlocProviders` widget but it has the advantage of making the code more readable. In the *providers* field, a list with three `BlocProvider` widgets is inserted. The first is of type `TabBloc`, the second is of type `StatsBloc` and the third is of type `FilteredTodoBloc`. The last two `BlocProvider` widgets need to be initialized passing a `TodoBloc` in the constructor. In order to retrieve the `TodoBloc`, the *of* method, provided by the `BlocProvider` widget, is used. The *of* method is called indicating the type of bloc to be searched and looks for the bloc in the current context. It rises an error in case a bloc of the specified type is not found in the context. Fortunately, we already set a `BlocProvider` of type `TodoBloc` in the parent widget, and so, the *of* method successfully finds it. The reason because the `TodoBloc` is positioned in an higher level with respect to the other blocs is that it is a good practice, to limitate the access to the state to the few parts of the application possible. This allows the state to be modified by the parts that has access to it only and, in case of problems, it is easier to understand which part of the code caused it.

**Source Code 2.100:** Todo app - Bloc - make other blocs accessible using a `MultiBlocProvider` widget

```

class MyApp extends StatelessWidget {
  const MyApp({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {

```

```

print("building: MATERIAL-APP");
return MaterialApp(
  initialRoute: "/",
  routes: {
    // usage of MultiBlocProvider
    "/": (context) => MultiBlocProvider(providers: [
      BlocProvider<TabBloc>(create: (context) => TabBloc()),
      BlocProvider<StatsBloc>(
        create: (context) =>
          StatsBloc(todoBloc:
            BlocProvider.of<TodoBloc>(context))),
      BlocProvider<FilteredTodoBloc>(
        create: (context) =>
          FilteredTodoBloc(todoBloc:
            BlocProvider.of<TodoBloc>(context))),
    ], child: const HomePage()),
    "/addTodo": (context) => const AddTodoPage(),
    "/updateTodo" : (context) => UpdateTodoPage(todo:
      (ModalRoute.of(context)!.settings.arguments as Todo)),
  },
);
}
}

```

**The state intergration inside the UI** - Now that the application's state has been defined and also made accessible in the interested part of the widgets trees is the moment to connect it with the UI.

**The HomePage** - The Scaffold widget is wrapped into a BlocBuilder widget. The BlocBuilder widget is used to access the state concerning the tab. Indeed, almost the entire HomePage is build on top of the tab value. The entire HomePage creation is moved inside the *builder* field of the BlocBuilder widget. Moreover, the type of the bloc and the type of states the BlocBuilder has to manage are specified in its declaration. Inside the function provided in the *builder* field ,indeed, we have access to the state in the form of an object of the type previously provided, in addition to the current context.



**Source Code 2.101:** Todo app - Bloc - wrapping the HomePage into a BlocBuilder

```
class HomePage extends StatelessWidget {
  const HomePage({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("building: HomePage");

    return BlocBuilder<TabBloc, TabState>( //use a BlocBuilder
      builder: (context, tabState) {
        return Scaffold(...);
      });
  }
}
```

Inside the function is possible to access the state of the tab through the variable *tabState* of type *TabState* and use it to build the Scaffold consequently.

**Source Code 2.102:** Todo app - Bloc - HomePage implementation

```
builder: (context, tabState) {
  //using the tabState
  return Scaffold(
    appBar: AppBar(
      title: const Text("TodoApp"),
      actions: [tabState == TabState.todos? // here
        VisibilityFilterComponent():Container()],
    ),
    //here
    body: tabState == TabState.todos ? const TodoView() : const Stats(),
    bottomNavigationBar: const TabSelector(),
    floatingActionButton: //here
      tabState == TabState.todos
        ? FloatingActionButton(
            child: const Icon(Icons.plus_one),
```

```

        onPressed: () {
          Navigator.pushNamed(context, "/addTodo");
        })
      : Container()

    );
  }

```

**The `TodoView` component** - The `TodoView` component needs to access the state of the filtered list and the filter only. The `ListView` widget is wrapped in a `BlocBuilder` widget. We define, using the `<>` notation, that it will handle the bloc of type `FilteredTodosBloc` and its internal state (of type `FilteredTodosState`). In the function passed in the *builder* field, the state is accessible using the variable called *filteredTodosState*. The actual type of the state is defined using an *if-else* statement. In case the state is of type `FilteredTodosLoadingState` a `CircularProgressIndicator` widget is returned. In case the state is of type `FilteredTodosLoadedState` a variable containing the list of todos will be available inside the `filteredTodosState` object and can be used to populate the `ListView` widget.

**Source Code 2.103:** Todo app - Bloc - `TodoView` implementation

```

class TodoView extends StatelessWidget {
  const TodoView({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    //using a BlocBuilder widget
    return BlocBuilder<FilteredTodosBloc, FilteredTodosState>(
      builder: (context, filteredTodosState) {
        print("building: TodoView");
        //depende on the current state
        if (filteredTodosState is FilteredTodosLoadedState) {
          return ListView.builder(
            itemCount: filteredTodosState.todos.length, //access it here

```

```

        itemBuilder: (context, index) {
          return TodoItem(
            todo: filteredTodoState.todos.elementAt(index)); //here
        });
      } else if (filteredTodoState is FilteredTodoLoadingState) {
        return const Center(child: CircularProgressIndicator());
      } else {
        return const Center(child: CircularProgressIndicator());
      }
    });
  }
}

```

**The TodoItem component** - Since this part of the development process does not consider any type of optimization, the TodoItem component does not need to be modified with respect to the implementation defined in Source Code 2.8. The todo instance to be visualized is passed as argument in the constructor from the ancestor widget (TodoView). However, even if the TodoItem component does not access the state to read any value it needs to access the state to emit an event. Once the checkbox is tapped, indeed, the list of todos should be modified. Emitting an event is easier than reading the state. It can be considered a constant action meaning that the widget should not be notified when the state changes. For this reason there is no need to use any BlocBuilder widget. It is sufficient to access the bloc, in which the event must be emitted, using the BlocProvider's *of* method, and emit the event. The Checkbox widget's *onChanged* function provides a Boolean variable (called *completed* in our case) that represents the value the Checkbox will take after being clicked. A new event of type SetCompletedTodoEvent is created, using this variable and the *id* of the todo passed by the parent, and emitted in the TodoBloc.

**Source Code 2.104:** Todo app - Bloc - TodoItem component *onChanged* field implementation

```

onChanged: (completed) {
  BlocProvider.of<TodoBloc>(context)

```

```
.add(SetCompletedTodoEvent(id, completed!));
}),
```

Summarizing ; once the Checkbox is pressed, inside a `TodoItem` , a new event in the bloc of the list of todos is generated. This event causes a state transition in the `TodoBloc` passing from the current state to a new state where the corresponding todo has been modified. Then, the bloc of the filtered list and the bloc of the stats, listening for changes in the `TodoBloc`, react emitting a new internal event (respectively of type `TodoUpdatedEvent` and `StatsUpdatedEvent`) . This event causes a state transition of the questioned blocs to a new state where the filtered list and the stats are computed using the new `TodoBloc`'s state. As a consequence of the change in the `FilteredTodosBloc` state , the `TodoView` component is notified and rebuilt showing the modification.

**The VisibilityFilterSelector component** - The `VisibilityFilterSelector` component depends only by the bloc of the filtered list and the filter. It just need to visualize the current filter and to update the state with a new filter in case a `DropDownMenuItem` is tapped. The `DropDownButton` is wrapped inside a `BlocBuilder` widget. The `BlocBuilder` widget is informed ,with the `<>` notation , it will handle the bloc of type `FilteredTodosBloc` and the states of type `FilteredTodoState`.

**Source Code 2.105:** Todo app - Bloc - `VisibilityFilterSelector` component implementation

```
return BlocBuilder<FilteredTodoBloc, FilteredTodoState>(
  builder: (context, filteredTodoState) {
```

Inside the *builder* field, a new variable of type `VisibilityFilter` is created and initialized based on the state of the `FilteredTodosBloc`. In case the state is of type `loaded` the variable is initialized with the current filter value. In case the state is of type `loading` the variable is initialized with the value *all*.

**Source Code 2.106:** Todo app - Bloc - populating a filter variable based of the current state in the `VisibilityFilterSelector` component

```
final VisibilityFilter filter= filteredTodoState is
  FilteredTodoLoadedState? filteredTodoState.filter:
  VisibilityFilter.all;
```

The `DropDownButton` is populated with the created filter variable. Notice that ,the function provided in the `onChange` field of every `DropDownMenuItem` widget, uses its internal filter value to create ,and emit, a new event in the `FilteredTodoBloc` of the type `FilteredTodoChangeFilterEvent`.

**Source Code 2.107:** Todo app - Bloc - `VisibilityFilterSelector` component `onChange` field implementation

```
onChanged: (filter) {
  BlocProvider.of<FilteredTodoBloc>(context)
    .add(FilteredTodoChangeFilterEvent(filter!));
},
```

**The `TabSelector` component** - The entire component depends only on the state of the tab. It needs to read and write the state. The `BottomNavigationBar` widget is wrapped inside a `BlocBuilder` widget. the `BlocBuilder` widget will handle the bloc of type `TabBloc` and the states of type `TabState`.

**Source Code 2.108:** Todo app - Bloc - `TabSelector` component implementation

```
return BlocBuilder<TabBloc, TabState>(
  builder: (context, currTab) {
    return BottomNavigationBar(
      currentIndex: TabState.values.indexOf(currTab),
```

The `BottomNavigationBar`'s `onTap` field is populated with a function that emits a new event of the type `ChangeTabEvent` ,inside the `TabBloc`, after the user taps the `BottomNavigationBarItem`.

**Source Code 2.109:** Todo app - Bloc - TabSelector component's *onTap* field implementation

```
onTap:
  (index)=>BlocProvider.of<TabBloc>(context)
    .add(ChangeTabEvent(TabState.values.elementAt(index))),
```

**The Stats component** - Also in this case, the only dependency the Stats component has is about the part of the state concerning the stats. The component is, therefore, wrapped into a BlocBuilder widget. The Blocbuilder widget will handle the bloc of type StatsBloc and the states of type StatsState. Inside the function provided into the *builder* field the type of the current state is checked. In case the state is of type StatsLoadedState , a widget of type Text is returned and populated using the *completed* variable contained inside the state object. In case the state is of type StatsLoadingState a CircularProgressIndicator widget is returned ,indicating that the stats still need to be computed.

**Source Code 2.110:** Todo app – Bloc - Stats component implementation

```
return BlocBuilder<StatsBloc, StatsState>(
  builder: (context, statsState) {
    return statsState is StatsLoadedState ?Center(
      child: Text(//show the stat value
        statsState.completed.toString()),
    ) : Center(child: const CircularProgressIndicator());
  },
);
```

## Features addition

New features presented HERE RIEFERIMENTO are now added to the base functionalities just implemented.

**New events** - The first thing to do is to make the state provide a way of adding and updating todos. Two new events are created and called `AddTodoEvent` and `UpdateTodoEvent` respectively. The `AddTodoEvent` will contain the name and the description to be used in the creation of the new todo instance. The id will be set by the method at the todo's addition in order to generate a unique one. The *completed* field will be set to false by default being the new todo obviously pending at its origin. The `UpdateTodoEvent` will contain the id of the todo to be modified and the new name and description. The list of todos is contained in the `TodoBloc`. Moreover, the `TodoBloc` handles events of the type `TodosEvent`. Both the `AddTodoEvent` and the `UpdateTodoEvent` are extended, though, with the `TodosEvent` abstract class in order to be manageable by the `TodoBloc`.

**Source Code 2.111:** Todo app - Bloc - `AddTodoEvent` and `UpdateTodoEvent` definition

```
class AddTodoEvent extends TodosEvent {
  final String name;
  final String desc;

  const AddTodoEvent(this.name, this.desc);

  @override
  String toString() => 'TodosEvent - AddTodoEvent';
}

class UpdateTodoEvent extends TodosEvent {
  final int id;
  final String newName;
  final String newDesc;

  const UpdateTodoEvent(this.id, this.newName, this.newDesc);

  @override
  List<Object> get props => [id, newName, newDesc];

  @override
  String toString() => 'TodosEvent - UpdateTodoEvent';
}
```

**TodoBloc update** - It necessary now to “teach” the TodoBloc at handling these new events. The workflow will be the following: when the `AddTodoEvent` is received in the `TodoBloc`, a new instance of the list of todos, contained in the current state, is generated. A new todo is created using the name and description contained in the event. The new todo is added to new instance of the list. The new list is then used to create a new state of the type `TodosLoadedState` before emitting it in the `TodoBloc`. When the `UpdateTodoEvent` is received in the `TodoBloc` a new instance of the list contained in the state is created. The todo with the id matching the one contained in the event is modified using the new name and description. Lastly, a state of type `TodosLoadedState` is emitted with the new list. There is one more thing to do, adding to the `TodoBloc`’s `mapEventToState` method two new *if-else* branches that check if the received event is of type `AddTodoEvent` or `UpdateTodoEvent`. In the first case the private method `mapTodoAddedToState` is called passing the event as parameter. In the second case the private method `mapTodoUpdatedToState` is called, instead, passing the event as parameter.

**Source Code 2.112:** Todo app - Bloc - `TodoBloc` `mapEventToState` extension for new events

```
@override
Stream<TodosState> mapEventToState(TodosEvent event) async* {
  if (event is LoadTodosEvent) {
    yield* _mapLoadTodosToState(event);
  } else if (event is AddTodoEvent) {//new branch
    yield* _mapTodoAddedToState(event);
  } else if (event is UpdateTodoEvent) {// new branch
    yield* _mapTodoUpdatedToState(event);
  } else if (event is SetCompletedTodoEvent) {
    yield* _mapSetCompletedToState(event);
  }
}
```

The `mapTodoAddedToState` method checks if the current state is of type `TodosLoadedState` ( if it is not is meaningless to perform any addition), then, creates a unique id and



a new instance of the list of todos contained in the *state* variable. It then adds the todo to the new list, Lastly, the *TodosLoadedState* created with the new list is emitted.

**Source Code 2.113:** Todo app - Bloc - *TodoBloc*'s *mapTodoAddedToState* method implementation

```
Stream<TodosState> _mapTodoAddedToState(AddTodoEvent event) async* {
  if (state is TodosLoadedState) {
    //generate new unique id
    int newId = generateId((state as TodosLoadedState).todos);
    //create new todo
    Todo newTodo = Todo(
      id: newId,
      name: event.name,
      description: event.desc + " " + newId.toString(),
      completed: false);
    //add it to a new list instance
    final List<Todo> updatedTodos =
      List.from((state as TodosLoadedState).todos)..add(newTodo);
    yield TodosLoadedState(updatedTodos);
  }
}
```

The *mapTodoUpdatedToState* method checks if the current state is of type *TodosLoadedState* ( if it is not is meaningless to perform any modification), then , creates a new instance of the list of todos contained in the *state* variable and modify the todo matching the id. Lastly, the *TodosLoadedState* created with the new list is emitted.

**Source Code 2.114:** Todo app - Bloc - *TodoBloc*'s *mapTodoUpdatedToState* method implementation

```
Stream<TodosState> _mapTodoUpdatedToState(UpdateTodoEvent event) async* {
  if (state is TodosLoadedState) {
    //replace the list with a new updated one
    List<Todo> newTodos = (state as TodosLoadedState)
```

```

        .todos
        .map((todo) => todo.id == event.id
            ? Todo(
                id: event.id,
                name: event.newName,
                description: event.newDesc,
                completed: false)
            : todo)
        .toList();
    yield TodosLoadedState(newTodos);
  }
}

```

**Access new feature in the UI** - The state can now handle this new functionalities correctly. Thanks to the fact that we situated the `TodoBloc` on top of the widgets tree it is possible now to access the state in the `AddTodoPage` and in the `UpdateTodoPage` easily. An instance of the `TodoBloc`, indeed, exists in the current context and can be accessed using the `of` method. In case the `TodoBloc` was located in a lower level with respect to the `MaterialApp` widget (from where routes are created) it would have had to be passed by argument to the corresponding pages. However, being the `TodoBloc` accessible, it can be used in the `AddTodoPage` to perform the todo addition, at the `TextButton`'s push, using the parameters contained in the `TextField` widgets. The `AddTodoPage` implementation is reported Source Code 2.142. The only part to be changed is the `onPressed` field of the `TextButton` widget. Inside the provided function, the `TodoBloc` instance is accessed using the `of` method and the `AddTodoEvent` emitted. The `AddTodoPage` is popped then to come back in the `HomePage`, where the `TodoView` rebuilds due to the change of the state of the `TodoBloc`.

**Source Code 2.115:** Todo app - Bloc - emitting an `AddTodoEvent` in the `AddTodoPage`

```

TextButton(
  onPressed: () {
    BlocProvider.of<TodoBloc>(context).add(AddTodoEvent(
      textControllerName.text, textControllerDesc.text));
  }
)

```

```
Navigator.pop(context);  
},  
child: const Text("Create"))
```

The same process is done to implement the `UpdateTodoPage`. In the `onPressed` field a function is provided. This function uses the `TextField` widgets's parameters to create and emit an event of type `UpdateTodoEvent`. The `UpdateTodoPage` is then popped and the `HomePage` rebuilt due to the `TodoBloc` state change.

**Source Code 2.116:** Todo app - Bloc - emitting an `UpdateTodoEvent` in the `UpdateTodoPage`

```
TextButton(  
  onPressed: () {  
    BlocProvider.of<TodoBloc>(context).add(UpdateTodoEvent(  
      widget.todo.id,  
      textControllerName.text,  
      textControllerDesc.text));  
    Navigator.pop(context);  
  },  
  child: const Text("Confirm"))
```

## Rendering optimization

To achieve the desired partial rendering is necessary to work on the `TodoView` and `TodoItem` widgets only. We will leverage on a specific field of the `BlocBuilder` widget called `buildWhen`. In this field is possible to insert a Boolean function in order to determine whether or not to rebuild the questioned widget on a state transition. Inside this function, the previous state and the next state can be accessed. For the moment, when a state change occurs, the `TodoView` widget destroys all the children `TodoItem` widgets and rebuilds them using the data contained in the new state. Well, actually is not precisely like this. Flutter indeed uses some articulated mechanism in order

to rebuild the few parts of the widget tree possible. From our perspective, however, `TodoItem` widgets are destroyed and recreated at every transaction, also in case a single `TodoItem` changed. To make the `TodoItem` widgets self-rebuild, it is necessary to make them sensible to changes in the state. For the moment, however, the `TodoItem` widget does not use any `BlocBuilder` widget at all. Indeed, it just visualizes the `todo` passed from the parent widget without actually accessing the state. The first thing to do is to wrap the `TodoItem` widget inside a `BlocBuilder` widget making it listen for changes in the `FilteredTodoBloc`. Instead of receiving, from the `TodoView` parent widget, a copy of the `todo` instance to be visualized is enough, now, to receive the `id` and use it to obtain the instance of the `todo` accessing the state. Inside the `builder` field, the function will look up for the corresponding `todo` in the list of filtered `todos` and use it to create the `TodoItem`.

**Source Code 2.117:** Todo app - Bloc - accessing the state into `TodoItem` component

```
class TodoItem extends StatelessWidget {
  final int id; //todo variable replaced with int one

  const TodoItem({Key? key, required this.id}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    //new BlocBuilder widget
    return BlocBuilder<FilteredTodoBloc, FilteredTodoState>(
      builder: (context, state) {
        print("building: Todo Item $id " + key.toString());

        if (state is FilteredTodoLoadedState) {
          //retrieve the instance of the todo from the state using the id
          Todo t = (state).todos.firstWhere((element) => element.id == id);
          //use it in the InkWell widget as usual
          return InkWell(. . .);
        } else {
          return Row(
            children: const [
              Text("ERROR"),
            ],
          );
        }
      },
    );
  }
}
```

```
    );
  }
});
```

At this point, both `TodoView` and `TodoItem` widgets listen for changes in the state. The `buildWhen` field, introduced above, is used now to teach them when to rebuild. Starting from the `TodoView` widget we provide a function to the `buildWhen` field that checks the types of the previous and the next state. If they are different there is no need to proceed further and a true value is returned meaning that the `TodoView` widget must be rebuilt. If they are equal the function checks if the length of the previous filtered list and the length of the new one are the same. If they differ it is necessary to rebuild the entire `TodoView` widget. In case they are equal the function proceeds checking if the elements contained in the first list are exactly the ones contained in the second. (note: it checks the ids only because we are not interested in knowing if the other field changed, the `TodoItem` will check it later) If all the elements are the same there is no need to rebuild the `TodoView` and the function terminates returning false.

**Source Code 2.118:** Todo app - Bloc - using the `buildWhen` field to perform exclusive rebuild in the `TodoView` component

```
return BlocBuilder<FilteredTodoBloc, FilteredTodoState>(
  buildWhen: (previous, next) {
    return !((previous is FilteredTodoLoadedState) &&
      (next is FilteredTodoLoadedState) &&
      //check if structural change occurred
      previous.todos.length == next.todos.length &&
      listEquals(next.todos.map((todo) => todo.id).toList(),
        previous.todos.map((todo) => todo.id).toList()));
  },
```

The same must be done in the `TodoItem` widget. The `TodoItem` needs to be rebuilt when the new list still contains the todo matching its id and, that todo, changed one or more of its internal fields: the name, the description or the completed field. A function is provided in the `buildWhen` field that checks if the previous and the next states are both of type `FilteredTodoLoadedState`. In case they aren't it is useless to rebuild the `TodoItem`

widget and so the false value is returned. In case they are the function checks if the new state contains the corresponding todo. In case it does not contains the todo it is useless to rebuild the TodoItem and so the false value is returned. In case it contains the todo the function checks if the todo changed its internal fields with respect to the previous state. In case it does the function returns true and the TodoItem is rebuilt.

**Source Code 2.119:** Todo app - Bloc - using the *buildWhen* field to perform exclusive rebuild in te TodoItem component

```
buildWhen: (previous, next) {
  if (next is FilteredTodoLoadedState &&
      previous is FilteredTodoLoadedState) {
    //check if the todo still exists
    if (next.todos.map((todo) => todo.id).toList().contains(id) == true) {
      //check if it is changed
      if (previous.todos.firstWhere((element) => element.id == id) ==
          next.todos.firstWhere((element) => element.id == id)) {
        return false;
      }
    } else {
      return false;
    }
  }
  return true;
}
```

## Conclusions

Table 2.3 reports some measurements taken from the InheritedWidget's implementation process. The *lines of code* column represents the lines of code added or updated with respect to the shared project structure proposed in subsection 2.2.1. The *time* column represents the time spent in order to implement the corresponding subprocess. The unit of measure **h** stands for hours and **m** stands for minutes. The *lines-time ratio* column

represents the average number of lines written in a minute. The *classes* column represents the number of created classes in each subprocess.

Measurement for Bloc process

	lines of code	time	lines/time ratio	classes
<b>base functionalities</b>	367	10-12 h	0.55 l/m	24
<b>feature addition</b>	67	15-20 m	3.94 l/m	2
<b>rendering optimization</b>	33	6-8 h	0.078 l/m	0

Table 2.3: BLoC measurements table

Figure 2.14 represents a pie chart showing the percentage of lines of code written in each implementation's process, including the one regarding the shared structure. The whole process is quite balanced in term of lines of code.

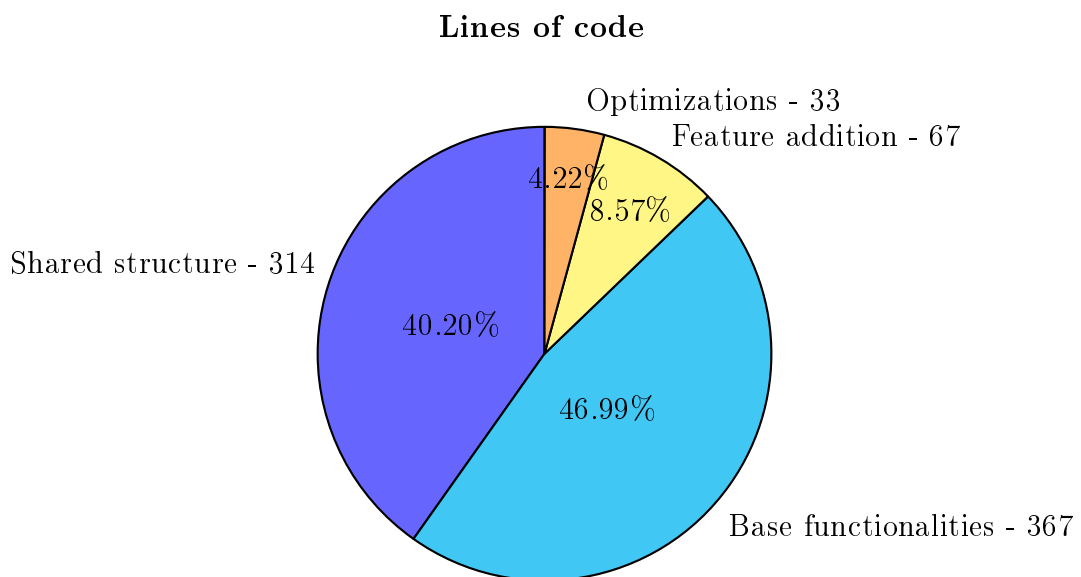


Figure 2.14: Shows the pie chart regarding the lines of code spent in each subprocess for the BLoC implementation

Figure 2.15 represents a pie chart showing the percentage of time spent in each implementation's process. Notice that the optimizations process took more than the 75% of the entire time.

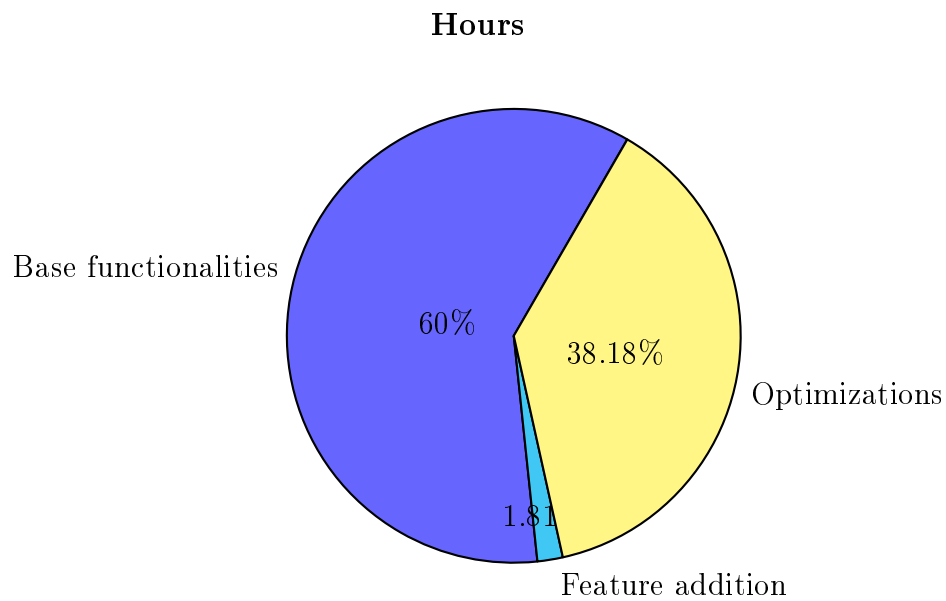


Figure 2.15: Shows the pie chart of the hours spent in each process for the BLoC implementation

Figure 2.16 shows the final folders structure for the InheritedWidget implementation. The only file added to the original folders structure is the `todo_provider.dart` file.



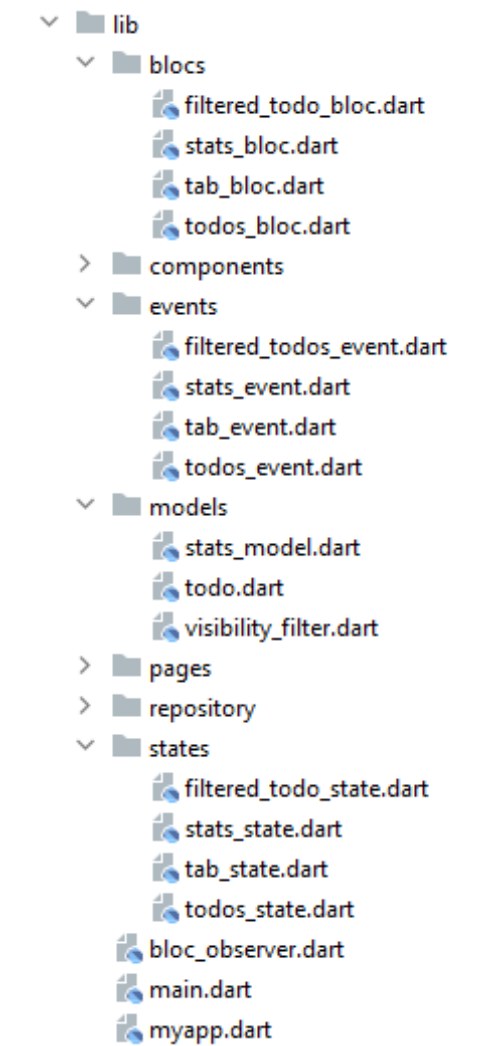


Figure 2.16: Shows the final folders structure for the BLoC implementation of the Todos app

Figure 2.17 represents the widget's tree structure for the InheritedWidget final application. Notice the TodoProvider widget, situated below the HomePage, providing an instance of the TodoInheritedData to the subtree.

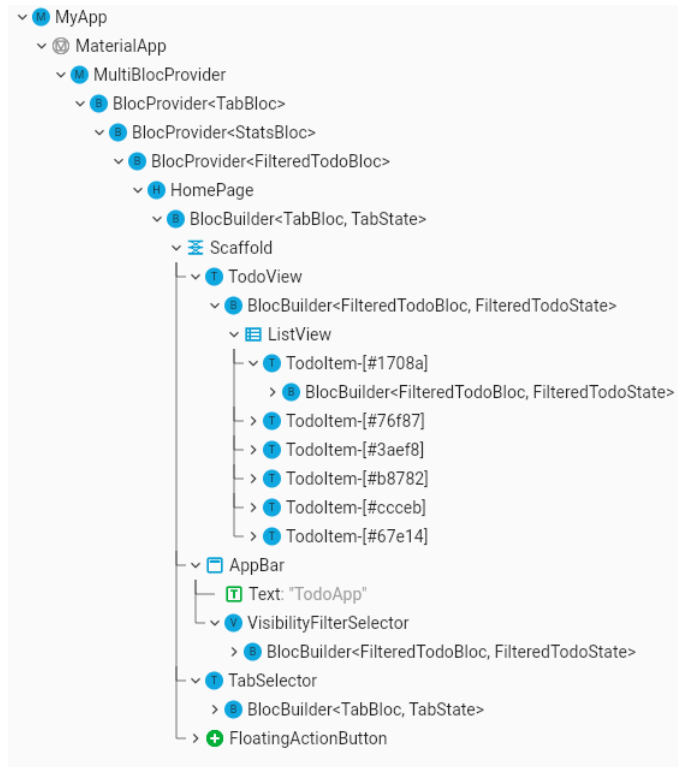
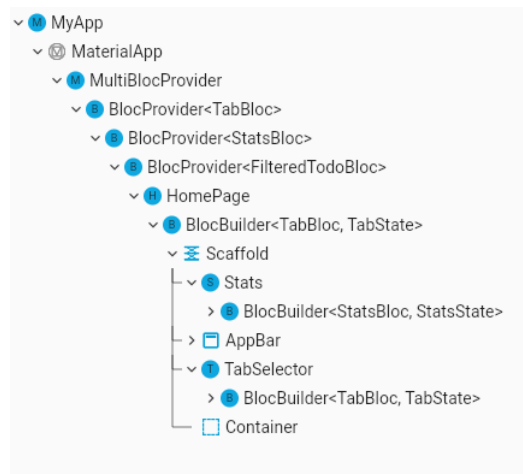
(a) Widgets tree structure *todos* tab(b) Widgets tree structure *stats* tab

Figure 2.17: Shows the widgets tree structure for BLoC Todos app

### 2.2.5. MobX implementation

Here start the implementation process that utilizes the MobX state management solution.

## Base functionalities

As mentioned in the Chapter XX RIFERIMENTO the MobX package makes one or more parts of the state Observable and uses a particular widget, called Observer, to keep track of changes in the observed variables. To be able to define observables is necessary to extend the interested class with the Store class offered by the package. Moreover, the container class must be made abstract. The usual definition of the Todo class is used momentarily remembering that no rendering optimizations are kept into account. The parts of the state to be made observable are: the list of todos, the filter and the tab value. The whole application, indeed, relies on them to track changes and update correspondingly.

**The observable state -** A new abstract class is created and called `_TodoStore`. It contains the list of todos and the filter. A separate observable variable will be used to implement the state of the tab. This design choice allows to show two different approaches the MobX package provides and divides the information regarding the todos from the information regarding the tab value. (the filter value is in some way connected with the list of todo). This new abstract class is extended with the Store class. A list of todos and a visibility filter are created inside it and annotated with the `@observable` syntax. The `@observable` annotation informs the code generator that those variables need to be made observable, moreover, the code generator automatically creates a getter and a setter action for them.

**Source Code 2.120:** Todo app - MobX- `TodoStore` abstract class implementation

```
//extend with the Store mixin to allow annotations
abstract class _TodoStore with Store {
  @observable
  List<Todo> todos = [];

  @observable
  VisibilityFilter filter = VisibilityFilter.all;
}
```

**Actions -** In this implementation the strict mode is set to “always”. This choice reflects the common usage of the pattern. It is indeed a common choice to allow state mutations

only through actions. This behavior comes with a lot of advantages that make it the correct choice for the major of the cases. This subject will be deeper investigated in the latter sections but, for the moment, it is worth noting that the mobx package also provides the possibility to configure the strict mode to “never” allowing to directly change the state without passing through an action. A bunch of new methods are added to the `TodoStore` class and marked with the `@action` annotation. The simplest one is the *changeFilter* method that allows to change the current filter.

**Source Code 2.121:** Todo app - MobX - `TodoStore`’s *changeFilter* action implementation

```
@action
void changeFilter(VisibilityFilter filter) {
    this.filter = filter;
}
```

A method to set the *completed* field of a particular todo is also required. This method is called *setCompleted* and takes the id of the todo to be changed and its new completed value. As usual, a new list is created, after modifying the todo, in order to allow mobx to recognize the change in the list of todos.

**Source Code 2.122:** Todo app - MobX - `TodoStore`’s *setCompleted* action implementation

```
@action
void setCompleted(int id, bool completed) {
    //check the todo's existence
    assert(todoExists(todos,id) ==true, 'No todo with id : \${id}');
    todos.where((element) => element.id==id).first.completed=completed;
}
```

The two usual methods to fetch and save the todos into the DataBase/repository are implemented and annotated with the `@action` annotation too.

**Source Code 2.123:** Todo app - MobX - TodoStore's *fetchTodos* and *saveTodos* actions implementation

```
@action
Future<void> fetchTodos() async {
    todos = await TodoRepository.loadTodos();
}

@action
Future<void> saveTodos() async {
    await TodoRepository.saveTodos(todos);
}
```

**Computed fields** - computed fields are the part of the state that can be derived from other parts of the state. They are pivotal in the mobx state management solution because the package is able to smartly compute them and to perform lot of optimizations under the hood using memoization technique to prevent useless computations. They are a similar concept with respect to selector in Redux. The list of completed todos is well suited to demonstrate the power of the computed field. A new getter function is created and called *completedTodos*. It computes the list of completed todos and returns it. The @computed annotation is positioned right above the method to make the code generator know how to implement it in order to perform the optimizations discussed earlier. During the application lifecycle the *completedTodos* method will be accessed numerous times and automatically recomputed in case a part of the state, it depends on, changes. Moreover, its value is memoized and reused in case multiple accesses are necessary. Another method is created in the same way to compute the *pendingTodos*.

**Source Code 2.124:** Todo app - MobX - TodoStore's *completedTodos* and *pendingTodos* computed values implementation

```
@computed
List<Todo> get completedTodos =>
    todos.where((element) => element.completed).toList();
```

```
@computed
List<Todo> get pendingTodos =>
  todos.where((element) => !element.completed).toList();
```

*pendingTodos* and *completedTodos* methods are then used to implement other computed values: the *filteredTodos*, the number of completed todos and the number of pending todos. The *filteredTodos* method returns the list of todos that match the visibility filter. It is composed using the computed values defined before. Also the *stats* value can be obtained using the computed feature.

**Source Code 2.125:** Todo app - MobX - *filteredTodos* and *stats* computed value implementation

```
@computed //compute todos list length
int get len => todos.length;

@computed //compute the completed todos
int get completed => completedTodos.length;

@computed //compute the pending todos
int get pending => pendingTodos.length;

@computed //compute the filtered list
List<Todo> get filteredTodos {
  switch (filter) {
    case VisibilityFilter.all:
      return todos;
    case VisibilityFilter.completed:
      return completedTodos;
    case VisibilityFilter.notCompleted:
      return pendingTodos;
  }
}

@computed //compute stats
```

```
String get stats {  
  return completed.toString();  
}
```

**The code generation** - The `_TodoStore` class won't be directly used in the code but its actual implementation will. The `_TodoStore` is, indeed, an abstract class and is used by the code generator to implement the actual `TodoStore` class. A particular line of code must be placed just below the imports to allow the code generator to recognize the abstract class to implement. This line of code uses the "part" syntax followed by the name of the file to be generated. The generated code will be putted inside a file called `counter.g.dart` which is included with the part directive right below the imports. Without this line, the code generator will not produce any output. The generated file contains the `_$TodoStore` mixin. It is combined with the `_TodoStore` abstract class to finally implement the `TodoStore`.

**Source Code 2.126:** Todo app - MobX - `TodoStore` code generation

```
//allow the code generator to create the todo_store.g.dart file  
part 'todo_store.g.dart';  
//use the generator file  
class TodoStore = _TodoStore with _$TodoStore;
```

In order to use the code generator and generate the code, a series of directives can be used into the terminal. For the sake of simplicity, the following line of code will be always used to generate code.

**Source Code 2.127:** Todo app - MobX - directive for code generation

```
flutter pub run build_runner watch --delete-conflicting-outputs
```

It automatically generates the code and handles all the possible conflicts that can arise. For example, in case a file named `todo_store.g.dart` already exists it first deletes the file

and then computes it again. With this line of code, the code generation process is made really easy. The drawback is that every time the code must be modified it is generated from scratch instead. In our case is not a big deal because the application is contained and the code generator only takes about 12-13 seconds to execute and generate the entire code. In a more spread scenario other directives can be used to make the code generation process lighter. I decided not to show the generated code because it is quite long and hard to read.

**The spy feature** - in order to enable the spy feature a new configuration for the *mainContext* must be provided before running the application, in the main function. After cloning the default *mainContext* the *isSpyEnabled* field is set to true and the *writePolicy* is set to always in order to enable the strict-mode for every state change. Moreover, a function must be passed to the spy feature. The code inside this function is execute every time a action occurs. It is, indeed, possible to perform arbitrary actions when events occurs. In our case is enough to print the event name when an event of type action occurs to have a clearer picture of what is going on.

**Source Code 2.128:** Todo app - MobX - spy feature attachment

```
//create a new configuration with strict mode set to "always"
mainContext.config = mainContext.config
    .clone(isSpyEnabled: true, writePolicy: ReactiveWritePolicy.always);
//provide a function to the spy feature
mainContext.spy((event) {
    if (event.type == "action") {
        print("event name : " + event.name);
    }
});
```

And that's basically all we need in order to implement the application's state. At this point is indeed already possible to test the state logic.

**Making the state accessible** - MobX, like every other solution used so far, uses a provider widget to supply the state to the subtree. In this case the mobx package do not self-implement the provider widget, instead it relies on an external package called *Provider* which offers this feature. The procedure is the usual one, the *MaterialApp*



widget is wrapped into a Provider widget of type `TodoStore` which supplies the instance of the `TodoStore` to the subtree. It has a *create* field where the `TodoStore` can be initialized and where the fetching of todos can take place.

**Source Code 2.129:** Todo app - MobX - making the state accessible using the Provider widget

```
//wrap the material app into a Provider widget
return Provider<TodoStore>(
  create: (_) => TodoStore()..fetchTodos(), //fetch todos at creation
  child: MaterialApp(. . .),
));
```

**The HomePage and the TabSelector component** - The `HomePage` is almost entirely built using the state's part regarding the tab. The first thing to do is to create an observable variable of type `TabState` to represent it. This time, a different approach with respect to the one used to implement the state of the todos and the filter, is used. We are not creating an abstract class neither generating any code. Moreover, no Provider widget is used because the tab value needs to be accessed only in a couple of widgets and passing it between them is way easier. The tab value is wrapped into an observable object of type `TabState`. The entire object is managed by the MobX package and the only difference with respect to a normal variable usage is that, in order to access the `TabState` value, we need to further dig into the *value* field instead of just using the tab variable as it is. Both the body and the `VisibilityFilterSelector` as well as the `TabSelector` depends on the tab value so the entire Scaffold widget is wrapped into a `Observer` widget. Once a change in the *tab* variable occurs, the `Observer` widget automatically determine which parts of the Scaffold widget should be rebuilt. In our case all components depends on the tab value and then every component is rebuilt once a tab change occurs. In cases some component are independent from the tab value and are wrapped into the observer widget they would not be rebuilt. The entire Scaffold is populated using the tab variable as usual. The only part that differs is the `TabSelector` component. Beside depending on the tab value it also need to change it. There are two equivalent options : passing the tab variable to the `TabSelector` component or passing a closure function. The first solution is used.

## Source Code 2.130: Todo app - MobX - HomePage implementation

```

class HomePage extends StatelessWidget {
  HomePage({Key? key}) : super(key: key);
  //new observable variable
  final _tab = Observable<TabState>(TabState.todos);

  @override
  Widget build(BuildContext context) {
    print("building HomePage");
    return Observer(//wrap the HomePage into a Observer widget
      builder: (context) {
        return Scaffold(
          appBar: AppBar(
            title: const Text("Todo App"),
            actions: [
              _tab.value == TabState.todos //access the state here
                ? const VisibilityFilterSelector()
                : Container()

            ],
          ),
          //access the state here
          body: _tab.value == TabState.todos ? const TodoView() :
            const Stats(),
          bottomNavigationBar: TabSelector(),
          floatingActionButton: _tab.value == //access the state here
            TabState.todos
              ? FloatingActionButton(...)
              : Container()

        );
      }
    );
  }
}

```

A new variable is added to the TabSelector widget and populated in the constructor. It is used in the *onTap* field's function to mutate the tab value once the user taps on one specific BottomNavigationBarItem. Notice that the state change is wrapped into a *runInAction* object. This because if we change the tab value directly, a run time error would arise alerting that observable values cannot be changed outside actions. This is due to the strict mode previously set to "always". *runInAction* creates a throwaway action we can use directly in the code. This approach is made necessary because we used a stand alone Observable variable. If we included the tab variable into the TodoStore class the code generator would had automatically create also its getter and setter actions.

**Source Code 2.131:** Todo app - MobX - TabSelector component implementation

```
class TabSelector extends StatelessWidget {
  //new variable passes from the HomePage
  final Observable<TabState> tab;

  const TabSelector({Key? key, required this.tab}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    print("building TabSelector");

    return BottomNavigationBar(
      //use it here
      currentIndex: TabState.values.indexOf(tab.value),
      onTap: (index) {
        //use a runInAction necessary for the strict mode
        runInAction(() => tab.value = TabState.values.elementAt(index));
      },
      items: (...),
    );
  }
}
```

**The VisibilityFilterSelector component** - It entirely depends on the value of the filter in the `TodoStore`. To obtain the instance of the `TodoStore` we use the static *of* method of the `Provider` widget specifying the type of the instance we are looking for. This procedure will be frequently used from now on and is usually performed at the beginning of the *build* method.

**Source Code 2.132:** Todo app - MobX - retrieving the `TodoStore`

```
final store = Provider.of<TodoStore>(context);
```

The entire `VisibilityFilterSelector` component is then populated using the filter variable contained in the `TodoStore` as usual and wrapped into an `Observer` widget to make it responsive to filter changes. In the *onChanged* field of the `DropDownMenuItem` widgets the *changeFilter* action previously defined is used to set the filter value to the tapped one.

**Source Code 2.133:** Todo app - MobX - `VisibilityFilterSelector` component implementation

```
return Observer( //wrap the VisibilityFilterSelector into a Observer widget
  builder: (context) {
    print("building Visibilityfilter");

    return DropDownButton<VisibilityFilter>(
      value: store.filter, //use the state here
      items: (...),
      onChanged: (tappedValue) {
        //change the state here
        store.changeFilter(tappedValue!);
      },
    );
  },
);
```

Notice that we could omit the usage of the *changeFilter* action and set the value of the

filter directly. This because a setter and a getter action are automatically created by the code generator for every observable field. This implies that the *changeFilter* action could also be omitted in the definition of the *ToDoStore* abstract class.

**Source Code 2.134:** Todo app - MobX - changing the state in the *VisibilityFilterSelector* without predefined action

```
onChanged: (tappedValue) {  
    //another way of changing the state  
    store.filter = tappedValue!;  
},
```

I personally dislike this feature MobX offers in the Flutter framework. I investigated a bit in the usage of MobX with React and JS finding that, in that case, it behaves as expected raising a warning in case a field is directly changed. (violating the strict mode) I find the way of changing the filter value proposed in the Source Code 2.133 a lot more elegant with respect to the one proposed in the Source Code 2.134. Explicitly using predefined actions, indeed, brings way more meaning for the reader and prevents programmers to accidentally mutate the state in the implementation process. Even if I prefer the first approach, in the end, both approaches pass through actions in order to change the state and this respect the MobX approach. Actions are, indeed, really important to the correct functioning of the application because using them allow the mobx package to generate atomic state transitions. Suppose a simple action, like the one we just used, produces reactions of different types and those reactions affects different parts of the state and the UI. Suppose now that the strict mode is disabled and set to "never". In that case can happen that the various reactions are completed/fired in different interval of time because their carried computation is heavier of lighter with respect of the others. Consequently the entire state of the application is not well synchronized and the UI could reflect this inconsistency bringing to a bad situations. Mobx package ensure that actions, and consequent reactions, are performed atomically without leaking any intermediate values as long as actions are used.

**The Stats component** - this component is really simple. It just needs to access the *ToDoStore* to get the *stats* value. The procedure shown in the Source Code 2.132 is used as usual to get an instance of the *ToDoStore* and, consequently, of the *stats* value. The entire widget is then wrapped into an *Observer* widget.

**Source Code 2.135:** Todo app - MobX - Stats component implementation

```
//retrive the state
final store = Provider.of<TodoStore>(context);
return Observer(//wrap the Stats component into an Observer widget
  builder: (context) {
    //access the state
    return Center(child: Text(store.stats));
  },
);
```

**The TodoView component and the TodoItem component** - These two components represent the core of the UI development process. Remember now that no optimizations are considered for the moment. The TodoView widget needs to access the state and rerender once a change in the `filteredList` of todos occurs. In this scenario, the MobX pattern really shines. It is sufficient to wrap the entire TodoView widget inside a Observer widget and access the filtered list of todo contained in the TodoStore to allow the MobX package to automatically detect a change in the filtered list. Once the list of todos or the filter is updated, the *filteredList* is automatically computed. As usual the TodoItem widget just acts as a visualizer for the corresponding todo and consequently takes as argument the todo instance to be visualized.

**Source Code 2.136:** Todo app - MobX - TodoView component implementation

```
//retrieve the state
final store = Provider.of<TodoStore>(context);
return Observer(//wrap the TodoView inside an Observer widget
  builder: (_) {
    print("building TodoView");

    return ListView.builder(
      itemCount: store.filteredTodos.length, //access the state here
      itemBuilder: (context, index) {
```

```
        return TodoItem( //access the state here
            todo: store.filteredTodos.elementAt(index),
        );
    },
);
},
);
```

The `TodoItem` widget implementation is the same presented 2.8 except for the *onChanged* field of the `TextButton` widget that needs to be filled up. The provided function retrieves the store using the `Provider` widget and fires the *setCompleted* action using the `todo`'s id and the new value for the *completed* field. Notice, that also in this case the *completed* field could be changed directly without any error.

**Source Code 2.137:** Todo app - MobX - changing the state in the `TodoItem` component's `Checkbox`

```
onChanged: (value) {
    //retrieve the state
    final store = Provider.of<TodoStore>(context);
    //change it
    store.setCompleted(todo.id, value!);
    // the state could also be changed using
    // todo.completed = value!;
},
```

The base functionalities are now working fine.

## Features addition

In order to add and update todos its necessary to define two new actions. Also in this case the creation of these two new actions could be avoided because setter and getter methods already exists for the list of todos. However , actions carry a lot more meaning and enable to avoid code duplication. Two new methods are added to the `TodoStore` class

and annotated with the `@action` syntax. The functioning is the usual one, in the *addTodo* method a new todo instance is created with an unique id and added to the list of todos. In the *updateTodo* method the id argument is used to search for the corresponding todo and the *name* and *desc* arguments are used to update it. Both methods need to substitute the todo's list with a new instance to allow the MobX package to recognize the change. Subsequently the code is generated again using the line of code presented in Source Code 2.127.

**Source Code 2.138:** Todo app - MobX - *updateTodo* action and *addTodo* action definition

```
@action
void updateTodo(int id, String name, String desc) {
    //check the todo existence
    assert(todoExists(todos,id) != null, 'No todo with id : \${id}');
    //update the todo
    Todo todo=todos.where((element) => element.id==id).first;
    todo.name=name;
    todo.description=desc;
}

@action
void addTodo(String name, String desc) {
    //generate a new id
    int newId = generateId(todos);
    //create a new todo instance
    Todo newTodo = Todo(
        id: newId,
        name: name,
        description: desc + " " + newId.toString(),
        completed: false);
    todos.add(newTodo);
    todos = todos.toList();
}
```

Accessing these new actions in the *UpdateTodoPage* and in the *AddTodoPage* is simple by the fact that the *Provider* widget has been positioned as parent of the *MaterialApp*



widget (from where different routes generate). In the *onPressed* field of the `TextButton`, situated in the `AddTodoPage`, the store is retrieved using the `Provider`'s *of* method and used to fire a action of type `addTodo`.

**Source Code 2.139:** Todo app - MobX - `AddTodoPage`'s *onPressed* field implementation

```
onPressed: () {  
  //retrieve the state  
  final store =  
    Provider.of<TodoStore>(context, listen: false);  
  //add the todo  
  store.addTodo(  
    textControllerName.text, textControllerDesc.text);  
  Navigator.pop(context);  
}
```

The same is done for the *onPressed* field of the `TextButton` in the `UpdateTodoPage`.

**Source Code 2.140:** Todo app - MobX - `UpdateTodoPage`'s *onPressed* field implementation

```
onPressed: () {  
  //retrieve the state  
  final store =  
    Provider.of<TodoStore>(context, listen: false);  
  //update the todo  
  store.updateTodo(widget.todo.id, textControllerName.text,  
    textControllerDesc.text);  
  Navigator.pop(context);  
},
```

## Rendering optimizations

Mobx package allows to perform the optimizations in an easy and direct way. All the effort is taken by the packages itself and the only thing to be cared about is to fragment the state in the most suited granularity for the purpose. In other words it is sufficient to make the state observable in the right points and wrap the corresponding UI elements into Observer widgets to get the job done. In the implementation provided so far for the list of todos, the only observable part was the list itself. The list is observed by the package and by the Observer widget contained in the TodoView. There is no concept of observability in the single todos yet and, once an instance of todo is changed, what is seen by the package is just a completely new list. Consequently, every Observer widget listening for changes in the todo list is rebuilt. The smallest observable element the package sees is the list itself. Said that, the first thing to do in order to optimize the renderings is to increase the granularity of the observed state. Not the list only but also every contained todo needs to be made observable. It is necessary though to redefine the todo model. This necessity arises with the usage of the mobx package and has not been faced in the other state management solutions used so far. The mobx state management solution introduces a dependency also in the data layer and in the model definition beside the usual dependency introduced in the business logic layer. In some scenarios this could represent an untoward drawback, for example in the porting processes. The Todo model class needs to be made abstract and to implement the Store behaviour as we did for the TodoStore. Now it is possible to annotate its internal fields with the @action syntax. All the fields except the id need to be observable. Moreover, the final attribute must be removed to all the observed variables. It is indeed meaningless to observe a variable that cannot be mutated.

### Source Code 2.141: Todo app - MobX - Todo model redefinition

```
//allow the code generation to create the todo.g.dart file
part 'todo.g.dart';

//use the generated file
class Todo = _Todo with _$Todo;

abstract class _Todo with Store{
```

```

    final int id;
    @observable
    String name;
    @observable
    String description;
    @observable
    bool completed;

    //the rest of the class is unchanged
    (...)
}

```

The `todo.g.dart` file is generated using the line of code presented in Source Code 2.127. The `TodoItem` widget is “stateless” for the moment. It receives a copy of the corresponding `todo` instance from the parent. We need to retrieve the instance directly from the store if we want the `Observer` widget to rebuild correctly and react to changes. Instead of receiving the entire `todo` from the parent the `id` field is enough. It is used then in the `build` method to access the corresponding `todo` instance in the store using the `Provider` widget. The remaining `TodoItem` code remains the same except for the fact that it is wrapped into an `Observer` widget.

**Source Code 2.142:** Todo app - MobX - access the state into `TodoItem` component

```

class TodoItem extends StatelessWidget {
    final int id; //todo variable is substituted with an int one

    const TodoItem({Key? key, required this.id}) : super(key: key);

    @override
    Widget build(BuildContext context) {
        //retrieve the state
        final store = Provider.of<TodoStore>(context, listen: false);
        //retrieve the todo matching the id
        final todo = store.todos.where((element) => element.id == id).first;
        return Observer(builder: (_) { //wrap the TodoItem into an Observer widget

```

```

    print("building TodoItem \${todo.id}");

    return InkWell(...);
  });
}
}

```

## Conclusions

Table 2.4 reports some measurements taken from the MobX's implementation process. The *lines of code* column represents the lines of code added or updated with respect to the shared project structure proposed in subsection 2.2.1. The *time* column represents the time spent in order to implement the corresponding subprocess. The unit of measure **h** stands for hours and **m** stands for minutes. The *lines-time ratio* column represents the average number of lines written in a minute. The *classes* column represents the number of created classes in each subprocess.

Measurement for MobX process

	lines of code	time	lines/time ratio	classes
<b>base functionalities</b>	92 (+106)	5-6 h	0.24 l/m	2 (+1)
<b>feature addition</b>	31 (+45)	10-15 m	1.82 l/m	0
<b>rendering optimization</b>	16 (+ 55)	30 m	0.53 l/m	1 (+1)

Table 2.4: MobX measurements table

Figure 2.18 represents a pie chart showing the percentage of lines of code written in each implementation's process, including the one regarding the shared structure. The whole process is quite balanced in term of lines of code.

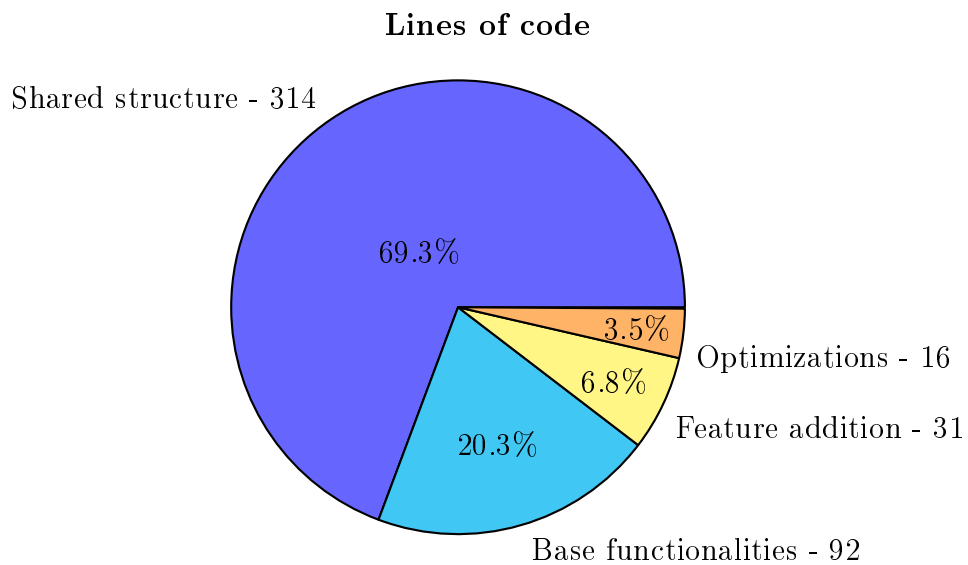


Figure 2.18: Shows the pie chart regarding the lines of code spent in each subprocess for the MobX implementation

Figure 2.19 represents a pie chart showing the percentage of time spent in each implementation's process. Notice that the most of the time has been spent understanding the solution and implementing the base functionalities.

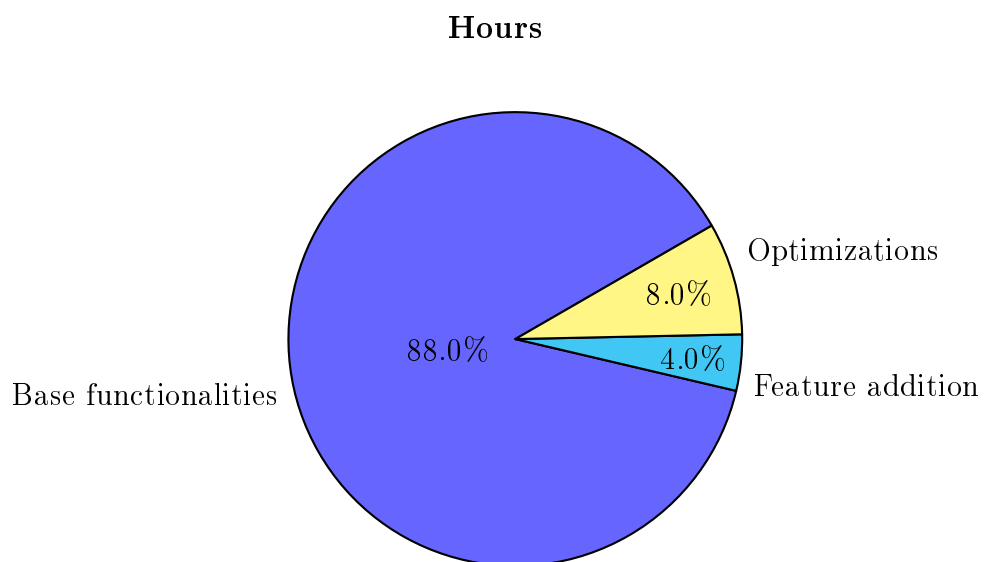


Figure 2.19: Shows the pie chart regarding the hours spent in each process for the MobX implementation

Figure 2.20 shows the final folders structure for the MobX implementation process. The only file added with respect to the original folders's structure is the `todo_store.dart` file

and the two generated files.

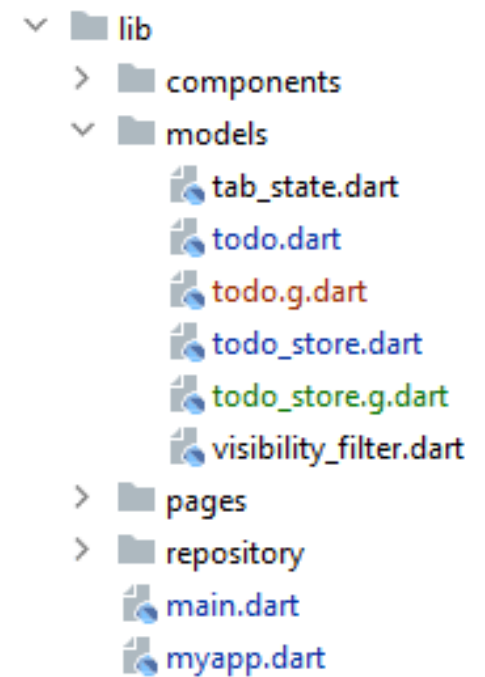


Figure 2.20: Shows the final folders structure for the MobX implementation of the Todos app

Figure 2.21 represents the widget's tree structure for the MobX final application. Notice the Provider widget, situated above the HomePage, providing an instance of the store to the subtree.

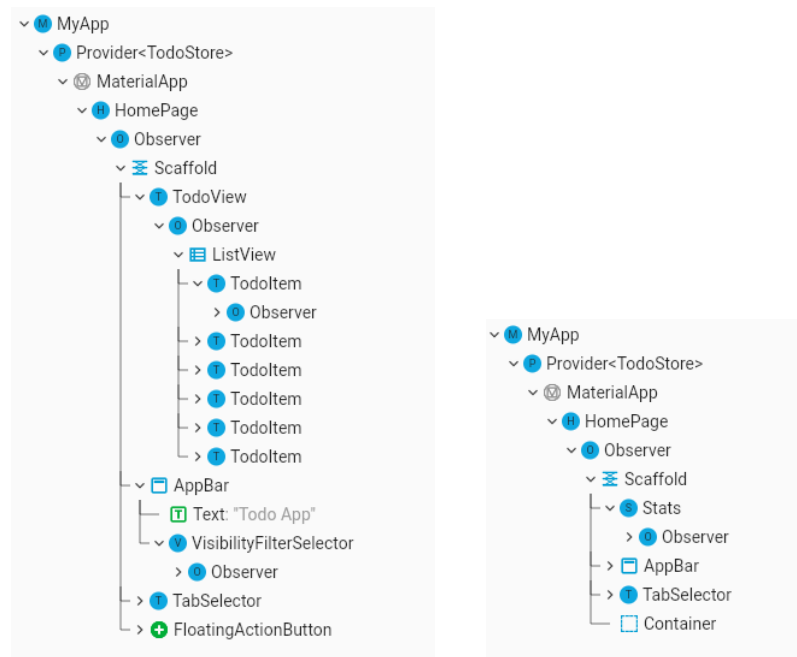
(a) Widgets tree structure *todos* tab(b) Widgets tree structure *stats* tab

Figure 2.21: Shows the widgets tree structure for MobX Todos app





## 3 | The Other app

Another app developed using same state managemnts solutions



## 4 | Comparisons

Some comparisons involving the data i kept and the other word file i have sent to you before



# 5 | Conslusions

Conclusions



# A | Appendix A

If you need to include an appendix to support the research in your thesis, you can place it at the end of the manuscript. An appendix contains supplementary material (figures, tables, data, codes, mathematical proofs, surveys, . . . ) which supplement the main results contained in the previous chapters.





## B | Appendix B

It may be necessary to include another appendix to better organize the presentation of supplementary material.



## List of Figures

2.1	Shows the HomePage's UI . . . . .	6
2.2	Shows the AddTodoPage's UI . . . . .	7
2.3	Shows the UpdateTodoPage's UI for the todo with id 741 . . . . .	7
2.4	Shows Todos app's shared files structure . . . . .	9
2.5	Shows the widgets tree structure in the AddTodoPage . . . . .	38
2.6	Shows the pie chart regarding the lines of code spent in each subprocess for the InheritedWidget implementation . . . . .	52
2.7	Shows the pie chart regarding the hours spent in each subprocess for the InheritedWidget implementation . . . . .	52
2.8	Shows the final folders structure for the InheritedWidget implementation of the Todos app . . . . .	53
2.9	Shows the widgets tree structure for InheritedWidget Todos app . . . . .	53
2.10	Shows the pie chart regarding the lines of code spent in each subprocess for the Redux implementation . . . . .	80
2.11	Shows the pie chart regarding the hours spent in each subprocess for the Redux implementation . . . . .	80
2.12	Shows the final folders structure for the Redux implementation of the Todos app . . . . .	81
2.13	Shows the widgets tree structure for Redux implementation of the Todos app . . . . .	82
2.14	Shows the pie chart regarding the lines of code spent in each subprocess for the BLoC implementation . . . . .	118
2.15	Shows the pie chart of the hours spent in each process for the BLoC im- plementation . . . . .	119
2.16	Shows the final folders structure for the BLoC implementation of the Todos app . . . . .	120
2.17	Shows the widgets tree structure for BLoC Todos app . . . . .	121
2.18	Shows the pie chart regarding the lines of code spent in each subprocess for the MobX implementation . . . . .	140

2.19	Shows the pie chart regarding the hours spent in each process for the MobX implementation . . . . .	140
2.20	Shows the final folders structure for the MobX implementation of the Todos app . . . . .	141
2.21	Shows the widgets tree structure for MobX Todos app . . . . .	142

# List of Tables

2.1	InheritedWidget measurements table . . . . .	51
2.2	Redux measurement table . . . . .	79
2.3	BLoC measurements table . . . . .	118
2.4	MobX measurements table . . . . .	139



## List of source codes

2.1	Todo app - MaterialApp and main function implementation . . . . .	9
2.2	Todo app - TabState model implementation . . . . .	10
2.3	Todo app - VisibilityFilter model implementation . . . . .	10
2.4	Todo app - Todo model implementation . . . . .	10
2.5	Todo app - Utility functions implementation . . . . .	12
2.6	Todo app - TodoRepository implementation . . . . .	12
2.7	Todo app - TodoView component implementation . . . . .	13
2.8	Todo app - TodoItem component implementation . . . . .	14
2.9	Todo app - TabSelector component implementation . . . . .	15
2.10	Todo app - VisibilityFilterSelector component implementation . . . . .	16
2.11	Todo app - Stats component implementation . . . . .	17
2.12	Todo app - HomePage implementation . . . . .	18
2.13	Todo app - UpdateTodoPage implementation . . . . .	19
2.14	Todo app - AddTodoPage implementation . . . . .	20
2.15	Todo app - InheritedWidget - extension to InheritedWidget . . . . .	22
2.16	Todo app - InheritedWidget- TodoInheritedData implementation . . . . .	22
2.17	Todo app - InheritedWidget - TodoInheritedData's <i>updateShouldNotify</i> method override . . . . .	23
2.18	Todo app - InheritedWidget - TodoInheritedData <i>of</i> method override . . .	24
2.19	Todo app - InheritedWidget - TodoProvider widget implementation . . . .	25
2.20	Todo app - InheritedWidget - TodoProvider 's <i>init</i> method implementation	26
2.21	Todo app - InheritedWidget - Data injection in the HomePage's subtree . .	26
2.22	Todo app - InheritedWidget - TodoView component implementation . . . .	27
2.23	Todo app - InheritedWidget - VisibilityFilterSelector component imple- mentation . . . . .	28
2.24	Todo app - InheritedWidget - TodoProvider's <i>onChangeFilter</i> field imple- mentation . . . . .	29
2.25	Todo app - InheritedWidget - TodoInheritedData widget expansion . . . .	30
2.26	Todo app - InheritedWidget - <i>onChangeFilter</i> function injection into TodoInheritedData widget . . . . .	30

2.27	Todo app - InheritedWidget - DropdownButton's <i>onChanged</i> field implementation . . . . .	31
2.28	Todo app - InheritedWidget - TodoProvider widget <i>onSetCompleted</i> function implementation . . . . .	31
2.29	Todo app - InheritedWidget - TodoItem's Checkbox <i>onChanged</i> field implementation . . . . .	32
2.30	Todo app - InheritedWidget - Stats component implementation . . . . .	33
2.31	Todo app - InheritedWidget - HomePage's <i>onTabChange</i> function implementation . . . . .	34
2.32	Todo app - InheritedWidget - TabSelector component implementation . . .	34
2.33	Todo app - InheritedWidget - TodoProvider's <i>onAddTodo</i> function implementation . . . . .	35
2.34	Todo app - InheritedWidget - <i>onAddTodo</i> function propagation . . . . .	36
2.35	Todo app - InheritedWidget - AddTodoPage's callback function parameter creation . . . . .	38
2.36	Todo app - InheritedWidget - "\addTodo" route parameters re-definition .	39
2.37	Todo app - InheritedWidget - AddTodoPage <i>onPressed</i> field implementation	39
2.38	Todo app - InheritedWidget - TodoProvider's <i>onUpdateTodo</i> function implementation . . . . .	40
2.39	Todo app - InheritedWidget - <i>onUpdateTodo</i> function propagation . . . . .	41
2.40	Todo app - InheritedWidget - UpdateTodoPage callback function parameter creation . . . . .	42
2.41	Todo app - InheritedWidget - UpdateTodoPageArguments class implementation . . . . .	42
2.42	Todo app - InheritedWidget - Using a UpdateTodoPageArguments instance to pass argument between routes . . . . .	43
2.43	Todo app - InheritedWidget - "\updateTodo" route re-definition . . . . .	43
2.44	Todo app - InheritedWidget - UpdateTodoPage <i>onPressed</i> field implementation . . . . .	44
2.45	Todo app - InheritedModel - extension to InheritedModel . . . . .	45
2.46	Todo app - InheritedModel - TodoInheritedData's <i>of</i> method implementation	45
2.47	Todo app - InheritedModel - TodoInheritedData's <i>updateShouldNotifyDepended</i> method implementation . . . . .	46
2.48	Todo app - InheritedModel - TodoInheritedData's <i>updateShouldNotifyDepended</i> method pseudocode . . . . .	48
2.49	Todo app - InheritedModel - accesing the state into TodoItem component .	50
2.50	Todo app - Redux - AppState model implementation . . . . .	54



2.51	Todo app - Redux - actions implementation for the fetching process . . . .	55
2.52	Todo app - Redux - SetCompletedTodoAction implementation . . . . .	55
2.53	Todo app - Redux - SetTabAction and SetVisibilityFilterAction implemen- tation . . . . .	56
2.54	Todo app - Redux - LoadTodoSuccedeedAction reducer implementation . .	57
2.55	Todo app - Redux - SetCompletedTodoAction reducer . . . . .	58
2.56	Todo app - Redux - todoReducer implementation using <i>combineReducers</i> function . . . . .	58
2.57	Todo app - Redux - todoReducer implementation using the traditional way	59
2.58	Todo app - Redux - tabReducer and visibilityFilterReducer implementation	59
2.59	Todo app - Redux - appStateReducer implementation . . . . .	60
2.60	Todo app - Redux - loadTodosMiddleware middleware implementation . .	61
2.61	Todo app - Redux - makes the Store accessible using a StoreProvider widget	62
2.62	Todo app - Redux - HomePage implementation . . . . .	64
2.63	Todo app - Redux - first level Selectors implementation . . . . .	65
2.64	Todo app - Redux - composed Selectors implementation . . . . .	66
2.65	Todo app - Redux - TodoView component implementation . . . . .	67
2.66	Todo app - Redux - TodoItem component's <i>onChanged</i> field implementation	68
2.67	Todo app - Redux - VisibilityFilterSelector component implementation . .	69
2.68	Todo app - Redux - TabSelector component implementation . . . . .	70
2.69	Todo app - Redux - Stats component implementation . . . . .	71
2.70	Todo app - Redux - AddTodoAction and UpdateTodoAction implementation	72
2.71	Todo app - Redux - addTodo reducer implementation . . . . .	72
2.72	Todo app - Redux - updateTodo reducer implementation . . . . .	73
2.73	Todo app - Redux - adding addTodo reducer and updateTodo reducer to the todoReducer . . . . .	73
2.74	Todo app - Redux - AddTodoPage <i>onPressed</i> field implementation . . . .	74
2.75	Todo app - Redux - UpdateTodoPage <i>onPressed</i> field implementation . . .	74
2.76	Todo app - Redux - accessing the state into TodoItem component . . . .	75
2.77	Todo app - Redux - TodoView component ad hoc ViewModel implementation	77
2.78	Todo app - Redux - ViewModel's equality operator override . . . . .	77
2.79	Todo app - Redux - TodoView component renders optimization . . . . .	78
2.80	Todo app - Bloc - states definition for the list of todos . . . . .	83
2.81	Todo app - Bloc - states definition for the filtered list of todos and the filter	84
2.82	Todo app - Bloc - states definition for the stats . . . . .	85
2.83	Todo app - Bloc - events definition for the list of todos . . . . .	86
2.84	Todo app - Bloc - events definition for the filtered list of todos and the filter	87

2.85	Todo app - Bloc - events definition for the stats and the tab . . . . .	89
2.86	Todo app - Bloc - TodoBloc implementation . . . . .	91
2.87	Todo app - Bloc - FilteredTodoBloc initialization . . . . .	93
2.88	Todo app - Bloc - FilteredTodoBloc subscription to TodoBloc stream . . .	94
2.89	Todo app - Bloc - FilteredTodoBloc <i>mapEventToState</i> method override . .	95
2.90	Todo app - Bloc - FilteredTodoBloc <i>_mapTodoChangeFilterEventToState</i> method implementation . . . . .	95
2.91	Todo app - Bloc - FilteredTodoBloc <i>_mapTodoUpdatedEventToState</i> method implementation . . . . .	96
2.92	Todo app - Bloc - FilteredTodoBloc <i>close</i> method implementation . . . . .	96
2.93	Todo app - Bloc - StatsBloc constructor implementation . . . . .	97
2.94	Todo app - Bloc - StatsBloc <i>mapEventToState</i> and <i>close</i> methods imple- mentation . . . . .	98
2.95	Todo app - Bloc - TabBloc implementation . . . . .	98
2.96	Todo app - Bloc - example of TodoBloc usage . . . . .	99
2.97	Todo app - Bloc - AppBlocObserver implementation . . . . .	100
2.98	Todo app - Bloc - setting the application's observer . . . . .	101
2.99	Todo app - Bloc - make the TodoBloc accessible using a BlocProvider widget	101
2.100	Todo app - Bloc - make other blocs accessible using a MultiBlocProvider widget . . . . .	102
2.101	Todo app - Bloc - wrapping the HomePage into a BlocBuilder . . . . .	103
2.102	Todo app - Bloc - HomePage implementation . . . . .	104
2.103	Todo app - Bloc - TodoView implementation . . . . .	105
2.104	Todo app - Bloc - TodoItem component <i>onChanged</i> field implementation .	106
2.105	Todo app - Bloc - VisibilityFilterSelector component implementation . . .	107
2.106	Todo app - Bloc - populating a filter variable based of the current state in the VisibilityFilterSelector component . . . . .	107
2.107	Todo app - Bloc - VisibilityFilterSelector component <i>onChange</i> field im- plementation . . . . .	108
2.108	Todo app - Bloc - TabSelector component implementation . . . . .	108
2.109	Todo app - Bloc - TabSelector component's <i>onTap</i> field implementation . .	108
2.110	Todo app - Bloc - Stats component implementation . . . . .	109
2.111	Todo app - Bloc - AddTodoEvent and UpdateTodoEvent definition . . . .	110
2.112	Todo app - Bloc - TodoBloc <i>mapEventToState</i> extension for new events . .	111
2.113	Todo app - Bloc - TodoBloc's <i>mapTodoAddedToState</i> method implementation	112
2.114	Todo app - Bloc - TodoBloc's <i>mapTodoUpdatedToState</i> method implemen- tation . . . . .	112

2.115	Todo app - Bloc - emitting an AddTodoEvent in the AddTodoPage . . . .	113
2.116	Todo app - Bloc - emitting an UpdateTodoEvent in the UpdateTodoPage .	114
2.117	Todo app - Bloc - accessing the state into TodoItem component . . . . .	115
2.118	Todo app - Bloc - using the <i>buildWhen</i> field to perform exclusive rebuild in te TodoView component . . . . .	116
2.119	Todo app - Bloc - using the <i>buildWhen</i> field to perform exclusive rebuild in te TodoItem component . . . . .	117
2.120	Todo app - MobX- TodoStore abstract class implementation . . . . .	122
2.121	Todo app - MobX - TodoStore's <i>changeFilter</i> action implementation . . . .	123
2.122	Todo app - MobX - TodoStore's <i>setCompleted</i> action implementation . . .	123
2.123	Todo app - MobX - TodoStore's <i>fetchTodos</i> and <i>saveTodos</i> actions imple- mentation . . . . .	123
2.124	Todo app - MobX - TodoStore's <i>completedTodos</i> and <i>pendingTodos</i> com- puted values implementation . . . . .	124
2.125	Todo app - MobX - <i>filteredTodos</i> and <i>stats</i> computed value implementation	125
2.126	Todo app - MobX - TodoStore code generation . . . . .	126
2.127	Todo app - MobX - directive for code generation . . . . .	126
2.128	Todo app - MobX - spy feature attachment . . . . .	127
2.129	Todo app - MobX - making the state accessible using the Provider widget .	128
2.130	Todo app - MobX - HomePage implementation . . . . .	128
2.131	Todo app - MobX - TabSelector component implementation . . . . .	130
2.132	Todo app - MobX - retrieving the TodoStore . . . . .	131
2.133	Todo app - MobX - VisibilityFilterSelector component implementation . .	131
2.134	Todo app - MobX - changing the state in the VisibilityFilterSelector with- out predefined action . . . . .	132
2.135	Todo app - MobX - Stats component implementation . . . . .	133
2.136	Todo app - MobX - TodoView component implementation . . . . .	133
2.137	Todo app - MobX - changing the state in the TodoItem component's Check- box . . . . .	134
2.138	Todo app - MobX - <i>updateTodo</i> action and <i>addTodo</i> action definition . . .	135
2.139	Todo app - MobX - AddTodoPage's <i>onPressed</i> field implementation . . . .	136
2.140	Todo app - MobX - UpdateTodoPage's <i>onPressed</i> field implementation . .	136
2.141	Todo app - MobX - Todo model redefinition . . . . .	137
2.142	Todo app - MobX - access the state into TodoItem component . . . . .	138



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