Creating a Formal Use Case Model for a Library Lending System

Loaning and Reserving Books as a Library Member

Module: Formal Specification and Refinement

Focus: Utilise Discrete Mathematical Concepts

A report originally created to fulfil the degree of

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Abstract

This paper utilises requirements engineering in order to develop a system for an agreed formal specification; a formal use case model for a library lending system. This is done through the use of formal methods and exploiting the power of discrete mathematics, in order to produce modular decomposition to create a hierarchical model. The report initially lays out the model by each class and an explanation of each function, followed by a formal use case model produced in LaTeX.

Contents

Initial Design of the Library System

The Membership Class: *LM*

The model begins by defining an invariant for a standard membership class, where members belong to a finite and initially empty set named *Member*. Each member has some associated information, and the types for both a member identifier and its associated information are specified as two given and fully abstract sets named $\mathbb{M}$ and $\mathbb{I}$. The initial condition for class *LM*, together with its invariant, imply that all components are empty when the class is first instantiated. A query is used to show the information associated with a member, and another that lists all the members. In both cases their pre-conditions have been set to clarify these specifications, by providing type information implicit from the invariant. The class also utilises events in order to add, update, or remove members.

LM	
Queries and Events	Explanation
LM?showInfo(m → i)	Shows the information of a member.
LM?showMembers(→ M)	Shows all the registered members.
LM!NewMember(i → M)	Adds a new member to the system.
LM!UpdateInfo(m, i)	Updates the information of a member.
LM!RemoveMember(m)	Removes a member from the system.

The Catalog Class: *LT*

The library's catalog can be modelled as an initially empty set of titles, where each title has an associated description. This class has a specification that is very similar to the previous one, except this time modelling information around library titles as opposed to library members. Queries are used to show the description of a book, as well as to show the entire library catalog.

LT	
Queries and Events	Explanation
LT?showDesc(t → d)	Shows the description of a selected title.
LT?showCatalog(→ T)	Shows the catalog of all titles in the system.
LT!NewTitle(d → t)	Adds a new title into the system.
LT!UpdateDesc(t, d)	Updates the description of a title.
LT!RemoveTitle(t)	Removes a title from the system.

The Collection Class: *LC*

The next stage of the model creates a library collection by extending the previous catalog class. A function is created to record the current number of copies for every title in the system and define a partition over the set of such titles. Titles are considered to be in the in-collection if there is at least copy of the title available, otherwise they are in the ex-collection. The *showDesc* query is promoted directly from the previous class *LT*, as queries at this level may be similar to those provided for a library catalog. Other state-components and initial-conditions are also inherited.

The *showCatalog* query on the other hand is redefined in order to include not only information about library tiles, but also to include the number of copies as well as its description. The *NewTitle* event is also extended from *LT*, in order to fix the number of initial copies to 0. To allow the system to be able to change this value, a new event that adds or remove copies of titles is included. Lastly, the *AddOrRemoveCopies* event is directly from *LT*, as no change is currently required at this level.

LC	
Queries and Events	Explanation
LC?showDesc(t → d)	Shows the description of a title.
LC?showNoCopies(t → n)	Shows the total number of copies of a title in the system.
LC?showInStockCollection(→ C)	Shows the titles currently in-collection.
LC?showOutStockCollection(→ C)	Shows the titles currently not in-collection.
LC!NewTitle(d, n → t)	Adds a new title into the system.
LC!AddOrRemoveCopies(t, n)	Alters the number of copies of a title.

The Loan Class: *LL*

A loan class is modelled by composing the previous classes *LM* and *LC*, where many of the queries and events at this level are simple promotions. These two classes are purposefully independent so that composing them will produce a consistent invariant. The model then extends their combined state, to define the set of all current loans, expressed mathematically in the model as a relation, and the numbers of available and loaned copies for each title in the system. A query is used to show the number of available copies of a title, and another to update the *showCollection* query from *LC*.

Another query that shows the set of members borrowing copies of a given title is also provided in this class. The *NewTitle* event has been expanded to show that the number of available and loaned copies is initially zero. The *AddOrRemoveCopies* event is also promoted from *LC* but is then further expanded upon to show how much the number of available copies is altered by. It is also given a pre-condition; a removed copy must be an available copy, otherwise the request is invalid.

LL	
Queries and Events	Explanation
LL?showInfo(m → i)	Shows the information of a member.
LL?showMembers(→ M)	Shows all the registered members.
LL?showDesc(t → d)	Shows the description of a title.
LL?showNoCopies(t → n)	Shows the total number of copies of a title in the system.
LL?availableCopies(t → n)	Shows the number of available title copies ready to be loaned.
LL?showInStockCollection(→ C)	Shows the titles currently in-collection.
LL?showOutStockCollection(→ C)	Shows the titles currently not in-collection.
LL?showLoans(t → M)	Shows the members currently borrowing copies of a title.
LL!NewMember(i → m)	Adds a new member to the system.
LL!UpdateInfo(m → i)	Updates the information of a member.
LL!NewTitle(d → t)	Adds a new title into the system.
LL!AddOrRemoveCopies(t, n)	Alters the number of copies of a title.
LL!LoanCopy(t, m)	Allows members to make loans of a title.
LL!Return(t, m)	Allows members to return loaned titles.

The Reservation Class: *LR*

LR is specified as a class parallel to *LL* to allow titles to be reserved. Later in the model, *LL* and *LR* will be composed together to produce a library system that is capable of both loans and reservations. To specify *LR*, the class *LM* and *LC* are exported and composed. A request queue function is created that delivers the sequence of members currently requesting a copy of a particular tile. Similar to loans in *LL*, reservations are defined as a relation. A query is created to show this information. The *NewTitle* event is also extended at this level, in order to create a new and initially empty request queue.

An event that allows member to reserve a particular title, as well as an event to cancel such a reservation have both been created. These two events preserve the relative ordering of all other pending requests whenever one for a title and member is either reserved or cancelled. They also give its new or previous position in the queue. When a member is removed, the system also makes sure that any of their reservations are also removed so the system is not left with a ghost request.

LR	
Queries and Events	Explanation
LR?showRequests(t → Q)	Shows the request queue for a given title.
LR!NewTitle(d → t)	Adds a new title into the system.
LR!Reserve(t, m → p)	Adds a member to the request queue for a given title.
LR!Cancel(t, m → p)	Removes a member from the request queue for a given title.

The Simple Library Class: *LS*

LL and *LR* are finally composed to produce a simple library class, with the majority of queries and events being direct promotions from previous classes. To maintain consistency, the model imposes a further constraint; for each title, a member may have at most one loan or reservation at one time.

LS	
Queries and Events	Explanation
LS?showInfo(m → i)	Shows the information of a member.
LS?showMembers(→ M)	Shows all the registered members.
LS?showDesc(t → d)	Shows the description of a title.
LS?showNoCopies(t → n)	Shows the number of copies of a particular title in the system.
LS?showLoans(t → M)	Shows the members currently borrowing copies of a title.
LS?showRequests(t → Q)	Shows the request queue for a given title.
LS!NewMember(i → m)	Adds a new member to the system.
LS!UpdateInfo(m → I)	Updates the information of a member.
LS!AddOrRemoveCopies(t, n)	Alters the number of copies of a title.
LS!NewTitle(d → t)	Adds a new title into the system.
LS!Reserve(t, m → p)	Adds a member to the request queue for a given title.
LS!Cancel(t, m → p)	Removes a member from the request queue for a given title.
LS!LoanCopy(t, m)	Allows members to make loans of a title.
LS!Return(t, m)	Allows members to return loaned titles.

The Formal Use Case Model

Membership Class: LM

$$\begin{array}{|l}
\multicolumn{1}{l}{LM} \\
\hline
Member : \text{set } \mathbb{M} \\
info : \text{Member} \rightarrow \mathbb{I} \\
\hline\hline
Member' = \emptyset \\
\hline
\end{array}$$

$$\begin{array}{|l}
\multicolumn{1}{l}{LM?showInfo(m \rightarrow i)} \\
\hline
i := info(m) \\
\hline
\end{array}$$

$$\begin{array}{|l}
\multicolumn{1}{l}{LM?showMembers(m \rightarrow i)} \\
\hline
M := info \\
\hline
\end{array}$$

$$\begin{array}{|l}
\multicolumn{1}{l}{LM!NewMember(i \rightarrow m)} \\
\hline
i : \mathbb{I};\; m : \mathbb{M};\; m \notin Member \\
\hline\hline
m \in Member'\,;\; info'(m) = i \\
\hline
\end{array}$$

$$\begin{array}{|l}
\multicolumn{1}{l}{LM!UpdateInfo(m, i)} \\
\hline
m : Member\,;\; i : \mathbb{I};\; i \neq info(m) \\
\hline\hline
info'(m) = i \\
\hline
\end{array}$$

$$\begin{array}{|l}
\multicolumn{1}{l}{LM!RemoveMember(m)} \\
\hline
m \in Member \\
\hline\hline
m \notin Member \\
\hline
\end{array}$$

Catalog Class: LT

LT

$$\begin{array}{|l}
Title : \text{set } \mathbb{T} \\
desc : Title \to \mathbb{D} \\
\hline\hline
Title' = \emptyset
\end{array}$$

$LT?showDesc(t \to d)$

$$\begin{array}{|l}
d := desc(t)
\end{array}$$

$LT?showCatalog(\to T)$

$$\begin{array}{|l}
T := desc
\end{array}$$

$LT!NewTitle(d \to t)$

$$\begin{array}{|l}
d : \mathbb{D}\,;\ t : \mathbb{T}\,;\ t \notin Title \\
\hline\hline
t \in Title'\,;\ desc'(t) = d
\end{array}$$

$LT!UpdateDesc(t, d)$

$$\begin{array}{|l}
t \in Title \\
\hline\hline
desc'(t) = d
\end{array}$$

$LT!RemoveTitle(t)$

$$\begin{array}{|l}
t \in Title \\
\hline\hline
t \notin Title
\end{array}$$

Collection Class: LC

LC

$$\begin{array}{|l}
\hline
LT \\
nc : Title \rightarrow \mathsf{NAT} \\
\{InColl, ExColl\} : \mathsf{part}\ Title \\
InColl := \{t : Title \bullet nc(t) > 0\} \\
\hline
\end{array}$$

$LC?showDesc(t \rightarrow d)$

$$\begin{array}{|l}
\hline
LT?showDesc(t \rightarrow d) \\
\hline
\end{array}$$

$LC?showNoCopies(t \rightarrow n)$

$$\begin{array}{|l}
\hline
n := nc(t) \\
\hline
\end{array}$$

$LC?showInCollection(\rightarrow C)$

$$\begin{array}{|l}
\hline
C : Title \nrightarrow \mathsf{POS} \times \mathbb{D} \\
C = \{(t, n, d) : InColl \times \mathsf{POS} \times \mathbb{D} \bullet n = nc(t) \wedge d = desc(t)\} \\
\hline
\end{array}$$

$LC?showOutCollection(\rightarrow C)$

$$\begin{array}{|l}
\hline
C : Title \nrightarrow \mathbb{D} \\
C = \{(t, d) : ExColl \times \mathbb{D} \bullet d = desc(t)\} \\
\hline
\end{array}$$

$LC!NewTitle(d, n \rightarrow t)$

$$\begin{array}{|l}
\hline
LT!NewTitle(d \rightarrow t) \\
\hline\hline
nc'(t) = n \\
\hline
\end{array}$$

$LC!AddOrRemoveCopies(t, n)$

$$\begin{array}{|l}
\hline
t : Title;\ n : \mathsf{INT};\ nc(t) + n \geq 0 \\
\hline\hline
nc'(t) = nc(t) + n \\
\hline
\end{array}$$

Loan Class: LL

LL

$$\begin{array}{|l}
LM\,;\ LC \\
loan : Title \leftrightarrow Member \\
na, nl : Title \to \mathsf{NAT} \\
\forall t : Title \bullet \\
\quad nc(t) = na(t) + nl(t) \wedge \\
\quad nl(t) = \#\{m : Member \bullet t \mapsto m \in loan\}
\end{array}$$

$LL?showInfo(m \to i)$

$$\begin{array}{|l} LM?showInfo(m \to i) \end{array}$$

$LL?showMembers(\to M)$

$$\begin{array}{|l} LM?showMembers(\to M) \end{array}$$

$LL?showDesc(t \to d)$

$$\begin{array}{|l} LC?showDesc(t \to d) \end{array}$$

$LL?showNoCopies(t \to n)$

$$\begin{array}{|l} LC?showMembers(\to M) \end{array}$$

$LL?availableCopies(t \to n)$

$$\begin{array}{|l} n := na(t) \end{array}$$

$LL?showInCollection(\to C)$

$$\begin{array}{|l}
C : Title \twoheadrightarrow \mathsf{POS} \times \mathsf{NAT} \times \mathbb{D} \\
C = \{(t, n, l, d) : InColl \times \mathsf{POS} \times \mathsf{NAT} \times \mathbb{D} \bullet \\
\qquad n = nc(t) \wedge l = nl(t) \wedge d = desc(t)\}
\end{array}$$

$LL?showOutCollection(\to C)$

$$\begin{array}{|l}
C : Title \twoheadrightarrow \mathbb{D} \\
C = \{(t, n, l, d) : ExColl \times \mathbb{D} \bullet l = nl(t) \wedge d = desc(t)\}
\end{array}$$

$LL?showLoans(t \to M)$

$$\begin{array}{|l} M := \{m : Member \bullet t \twoheadrightarrow m \in loan\} \end{array}$$

$LL!NewMember(i \to m)$

$$\begin{array}{|l} LM!NewMember(i \to m) \end{array}$$

$LL?UpdateInfo(m, i)$

$LM!UpdateInfo(m, i)$

$LL!NewTitle(d, n \rightarrow t)$

$LC?NewTitle(d, n \rightarrow t)$

$LL!AddOrRemoveCopies(t, n)$

$LC!AddOrRemoveCopies(t, n)$

$LL!LoanCopy(t, m, n)$

$t : Title;\ m : Member;\ n : nl(t$

$t \mapsto m \notin loan$

$na(t) > 0$

$nl(t) > 0$

$t \mapsto m \in loan'$

$LL!Return(t, m)$

$t \mapsto m : loan$

$t \mapsto m \notin loan'$

$LL?memberLoaning(m \rightarrow T)$

$T := t : Title \bullet m \mapsto t \in loan$

$LL!RemoveMember(m)$

$m \mapsto t \notin loan$

$LM!RemoveMember(m)$

$LL!RemoveTitle(t)$

$t \mapsto m \notin loan$

$LT!RemoveTitle(t)$

Reservation Class: LR

LR

$$\begin{array}{|l}
LM\,;\ LC \\
requestQ : Title \to int \cdot \mathsf{seq}\ Member \\
reserve : Title \leftrightarrow Member \\
\mathsf{cf}\ reserve = \mathsf{cod} \circ requestQ \\
nQ := (\#) \circ requestQ \\
\hline
\end{array}$$

$LR!NewTitle(d, n \to t)$

$$\begin{array}{|l}
\hline
LC?NewTitle(d, n \to t) \\
\hline\hline
requestQ'(t) = \langle\rangle \\
\hline
\end{array}$$

$LR!Reserve(t, m \to p)$

$$\begin{array}{|l}
\hline
t : Title\,;\ m : Member\,;\ p : \mathsf{POS} \\
t \mapsto m \notin reserve\,;\ p = nQ(T) + 1 \\
\hline\hline
requestQ'(t) = (requestQ(t))\langle m\rangle \\
nQ'(t) = p \\
t \mapsto m \in reserve' \\
\hline
\end{array}$$

$LR!Cancel(t, m \to p)$

$$\begin{array}{|l}
\hline
t : Title\,;\ m : Member\,;\ p : \mathsf{POS} \\
t \mapsto m \in reserve \\
Q_1\langle m\rangle Q_2 := requestQ(t) \\
p = \#Q_1 + 1 \\
\hline\hline
requestQ'(t) = Q_1\langle\rangle Q_2 \\
nQ'(t) = nQ(t) - 1 \\
t \mapsto m \notin reserve' \\
\hline
\end{array}$$

$LR!RemoveMember(m)$

$$\begin{array}{|l}
\hline
m \mapsto t \notin reserve \\
\hline\hline
LM!RemoveMember(m) \\
\hline
\end{array}$$

$LR!RemoveTitle(t \to m)$

$$\begin{array}{|l}
\hline
LR!Cancel(t, m \to p) \\
LT!RemoveTitle(t) \\
\hline
\end{array}$$

Simple Library Class: LS

LS

$$\boxed{\begin{array}{l} LL;\ LR \\ loan \cap reserve = \emptyset \end{array}}$$

$LS?showInfo(m \rightarrow i)$

$$\boxed{LM?showInfo(m \rightarrow i)}$$

$LS?showMembers(\rightarrow M)$

$$\boxed{LM?showMembers(\rightarrow M)}$$

$LS?showDesc(t \rightarrow d)$

$$\boxed{LT?showDesc(t \rightarrow d)}$$

$LS?showNoCopies(t \rightarrow n)$

$$\boxed{LC?showMembers(\rightarrow M)}$$

$LS?showNoCopies(t \rightarrow n)$

$$\boxed{LC?showMembers(\rightarrow M)}$$

$LS?showLoans(t \rightarrow M)$

$$\boxed{LL?showLoans(t \rightarrow M)}$$

$LS?showRequests(t \rightarrow Q)$

$$\boxed{LR?showRequests(t \rightarrow Q)}$$

$LS?showInCollection(\rightarrow C)$

$$\boxed{\begin{array}{l} C : Title \nrightarrow \mathsf{POS} \times \mathsf{NAT} \times \mathsf{NAT} \times \mathbb{D} \\ C = \{(t, n, l, q, d) : InColl \times \mathsf{POS} \times \mathsf{NAT} \times \mathsf{NAT} \times \mathbb{D} \bullet \\ \qquad n = nc(t) \land l = nl(t) \land q = nQ(t) \land d = desc(t)\} \end{array}}$$

$LS?showOutCollection(\rightarrow C)$

$$\boxed{\begin{array}{l} C : Title \nrightarrow \mathbb{D} \\ C = \{(t, n, l, q, d) : ExColl \times \mathbb{D} \bullet l = nl(t) \land q = nQ(t) \land d = desc(t)\} \end{array}}$$

$LS!NewMember(i \to m)$

$$\boxed{LM!NewMember(i \to m)}$$

$LS!RemoveMember(m)$

$$\boxed{LR!RemoveMember(m)}$$

$LS?UpdateInfo(m, i)$

$$\boxed{LM!UpdateInfo(m, i)}$$

$LS!AddOrRemoveCopies(t, n)$

$$\boxed{LL!AddOrRemoveCopies(t, n)}$$

$LS!NewTitle(d, n \to t)$

$$\boxed{\begin{array}{l} LL!NewTitle(d, n \to t) \\ LR!NewTitle(d, n \to t) \end{array}}$$

$LS!RemoveTitle(t \to m)$

$$\boxed{LR!RemoveTitle(t \to m)}$$

$LS!Reserve(t, m \to p)$

$$\boxed{\begin{array}{l} LR!Reserve(t, m \to p) \\ t \mapsto m \notin loan \end{array}}$$

$LS!Cancel(t, m \to p)$

$$\boxed{LR!Cancel(t, m \to p)}$$

$LS!LoanCopy(t, m)$

$$\boxed{\begin{array}{l} LL!LoanCopy(t, m) \\ n : (NAT)\, ;\ na(t) > n \\ \boxed{\begin{array}{l} t \mapsto m \notin reserve\, ;\ n = nQ(t) \\ \hline\hline LR!Cancel(t, m \to p) \\ n = p - 1 \end{array}} \end{array}}$$

$LS!Return(t, m)$

$$\boxed{LL!Return(t, m)}$$

Evaluation

The formal model that I have developed allows users members and their relevant information to be added, modified, or removed from a library system. The system can also add, modify, or remove any book alongside its relevant information. The user can check to see how many of any given book title is currently in stock. The system also allows members to loan or reserve library books through the use of queues. All of these functions are all split up into multiple classes to allow for easy promotion between them when required. Each of the models queries and events are then unified into one class at the end of the model for ease of use for any user of the system. All of this has been completed in order to meet the requirements for creating a formal use case model for a library lending system.

Reflection

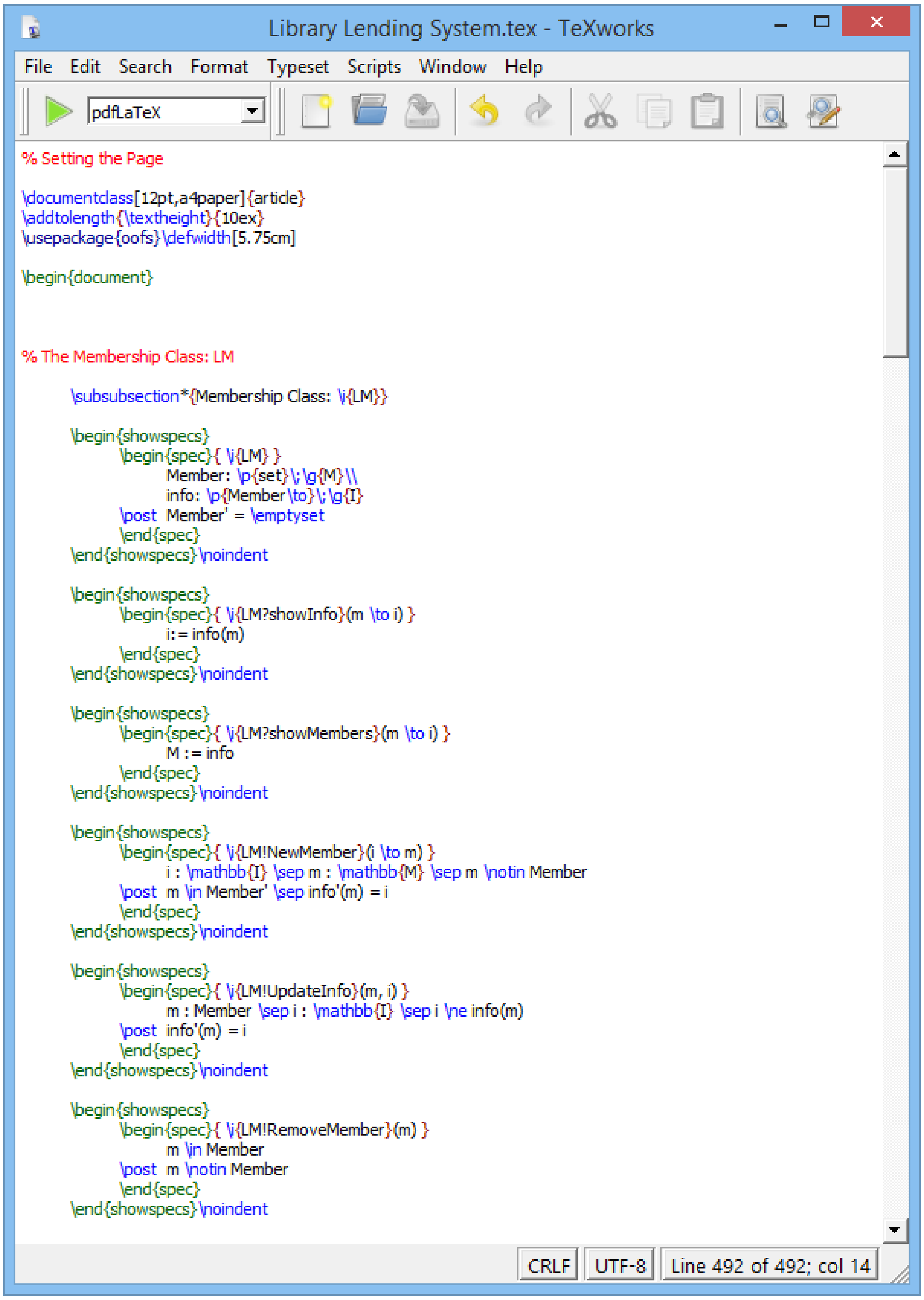
Upon reflection of my work, I feel that I have improved my understanding of the concepts and constraints of the provided formal model. I was able to achieve this by implementing various queries and events in order to provide required features for the model to function. I also learned how to use LaTeX in order to produce the layout of the use case, as seen in **Appendix A**. If I were to attempt a task similar to this one again in the future, I would research further into how dates can be used to implement other features, such as titles being listed as lost if unreturned after a predefined period. Overall, I am happy with the new modelling techniques I have developed, by formalizing system requirements and developing a formal model of an example library system at an abstract level.

References

The LaTeX Team. (2020, July). Retrieved from The LaTeX Project: https://www.latex-project.org/

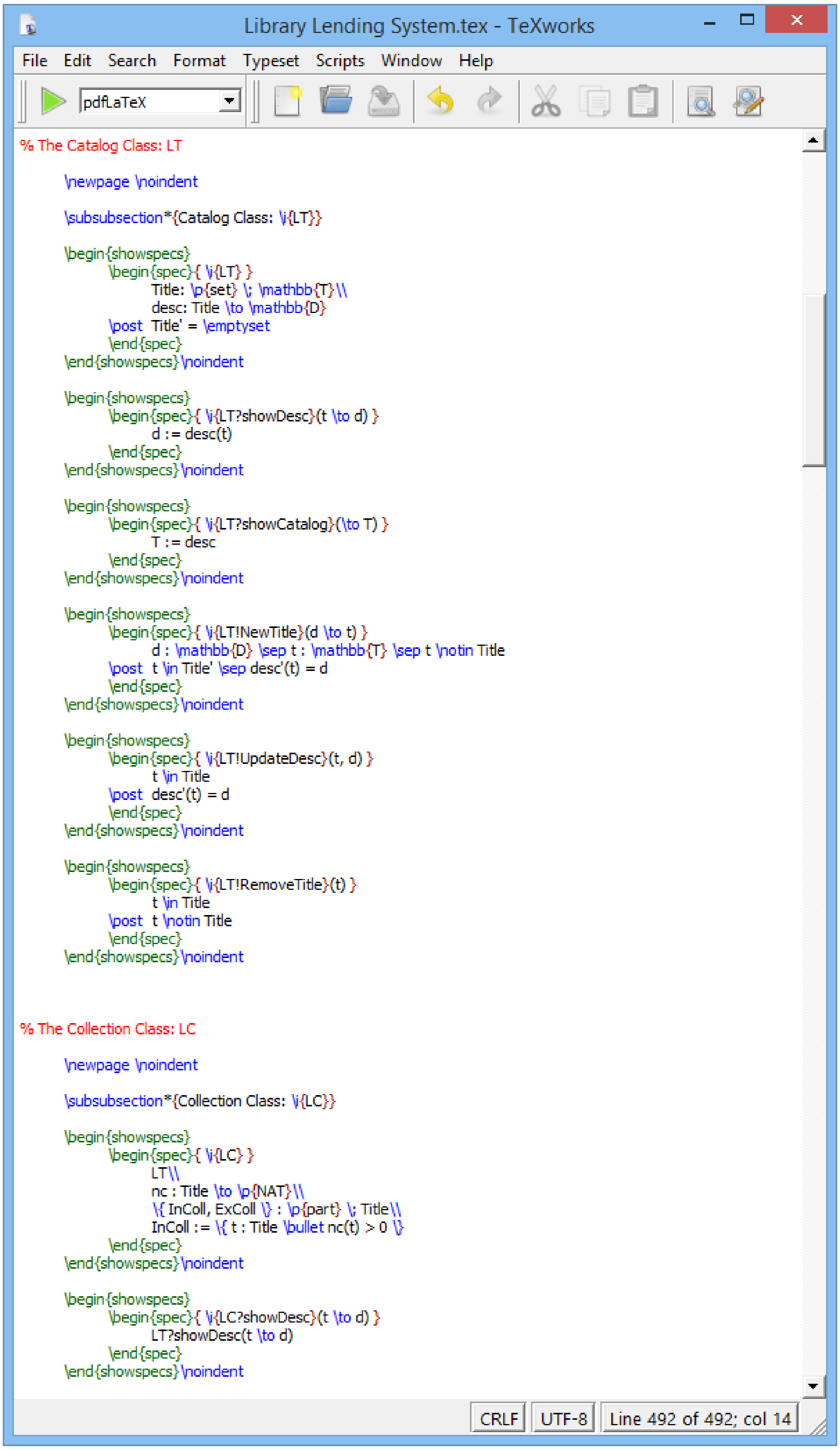
Appendices

Appendix A – The LaTeX Code for Creating the Formal Use Case Model

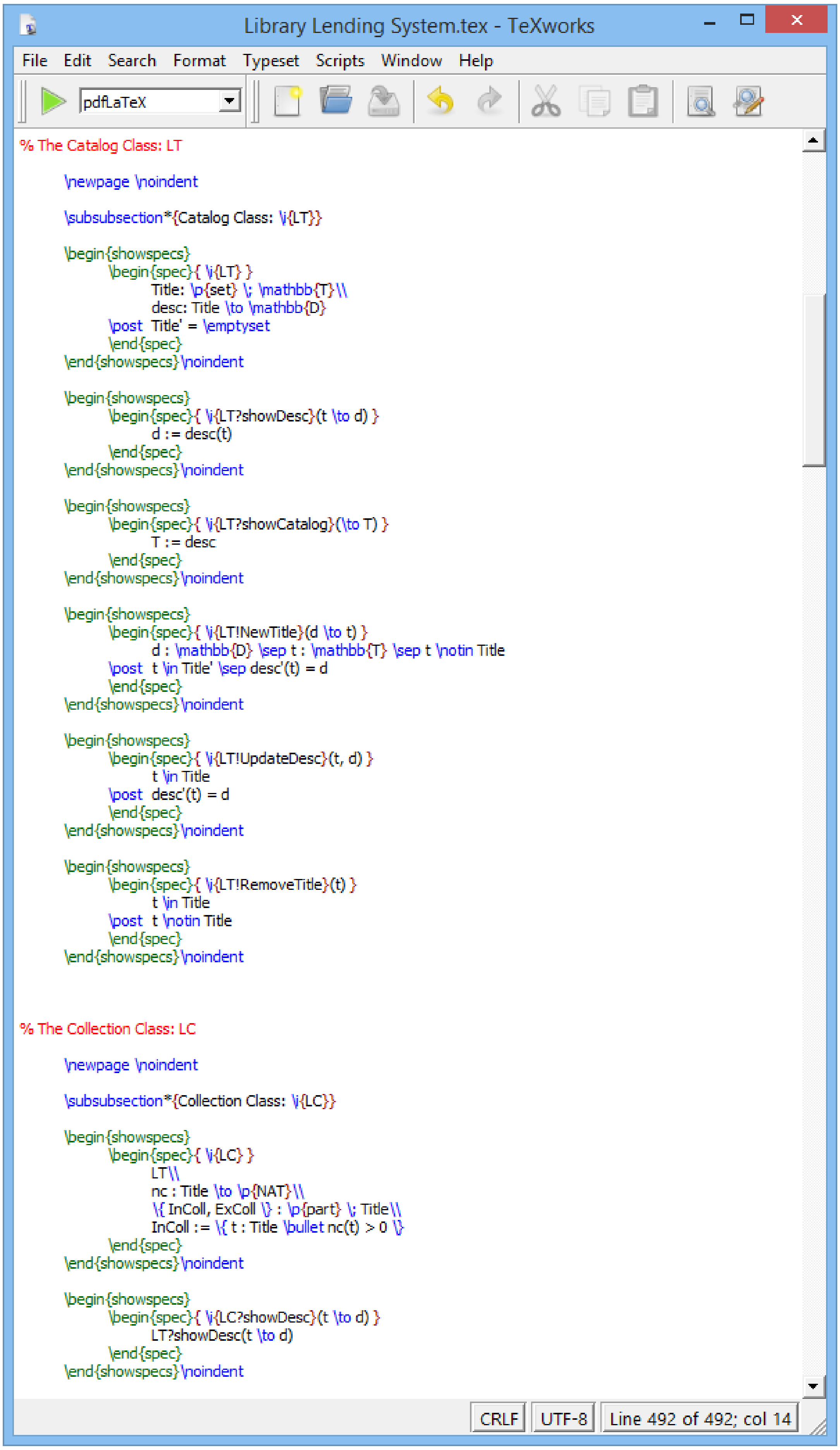

Library Lending System.tex - TeXworks
File Edit Search Format Typeset Scripts Window Help
pdfLaTeX

```
% Setting the Page

\documentclass[12pt,a4paper]{article}
\addtolength{\textheight}{10ex}
\usepackage{oofs}\defwidth[5.75cm]

\begin{document}


% The Membership Class: LM

        \subsubsection*{Membership Class: \i{LM}}

        \begin{showspecs}
                \begin{spec}{ \i{LM} }
                        Member: \p{set}\;\g{M}\\
                        info: \p{Member\to}\;\g{I}
                \post  Member' = \emptyset
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LM?showInfo}(m \to i) }
                        i:= info(m)
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LM?showMembers}(m \to i) }
                        M := info
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LM!NewMember}(i \to m) }
                        i : \mathbb{I} \sep m : \mathbb{M} \sep m \notin Member
                \post  m \in Member' \sep info'(m) = i
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LM!UpdateInfo}(m, i) }
                        m : Member \sep i : \mathbb{I} \sep i \ne info(m)
                \post  info'(m) = i
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LM!RemoveMember}(m) }
                        m \in Member
                \post  m \notin Member
                \end{spec}
        \end{showspecs}\noindent
```

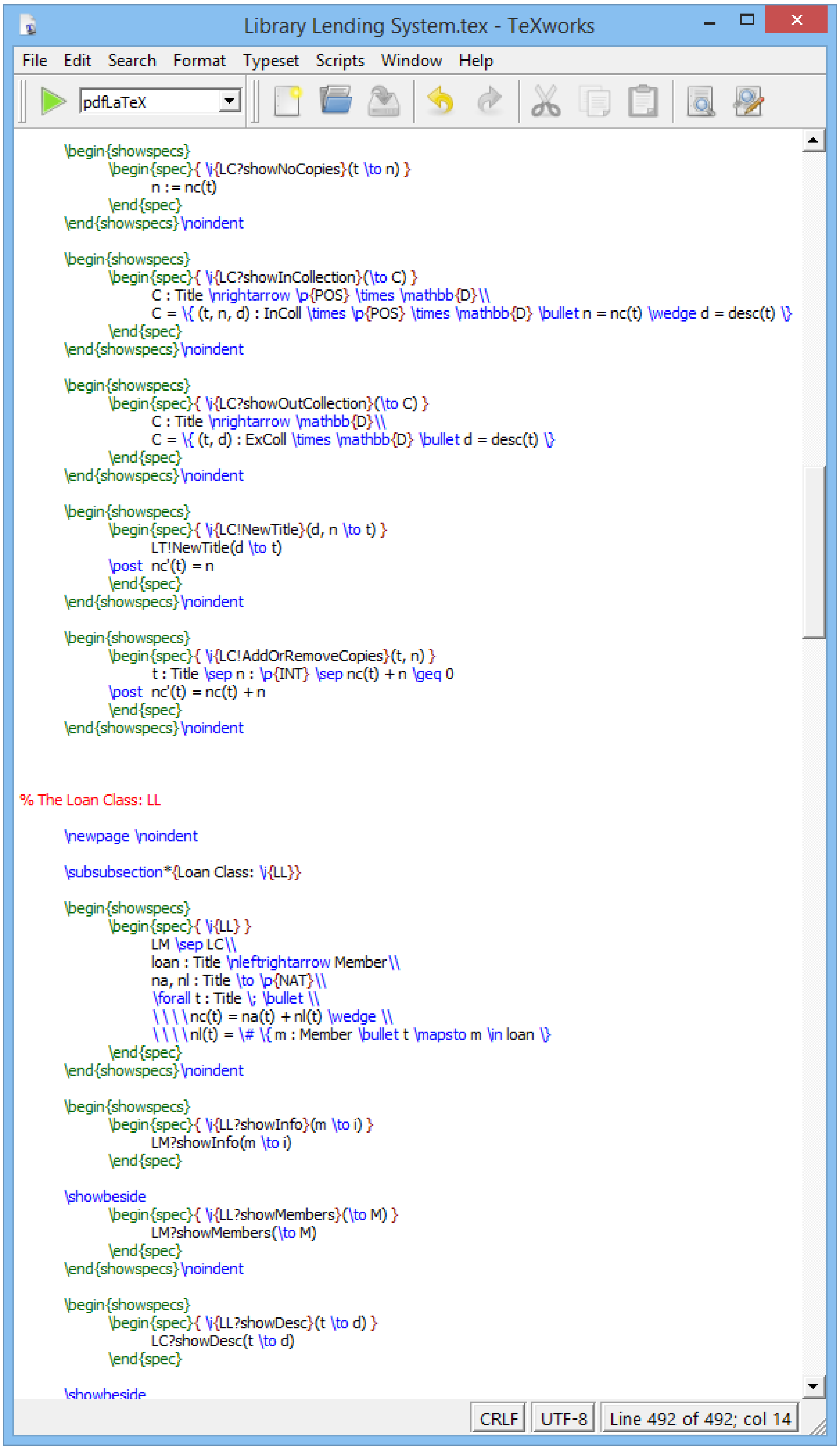
CRLF | UTF-8 | Line 492 of 492; col 14


Library Lending System.tex - TeXworks
File Edit Search Format Typeset Scripts Window Help
pdfLaTeX
CRLF UTF-8 Line 492 of 492; col 14

```
% The Catalog Class: LT

        \newpage \noindent

        \subsubsection*{Catalog Class: \i{LT}}

        \begin{showspecs}
                \begin{spec}{ \i{LT} }
                        Title: \p{set} \; \mathbb{T}\\
                        desc: Title \to \mathbb{D}
                \post  Title' = \emptyset
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT?showDesc}(t \to d) }
                        d := desc(t)
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT?showCatalog}(\to T) }
                        T := desc
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!NewTitle}(d \to t) }
                        d : \mathbb{D} \sep t : \mathbb{T} \sep t \notin Title
                \post  t \in Title' \sep desc'(t) = d
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!UpdateDesc}(t, d) }
                        t \in Title
                \post  desc'(t) = d
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!RemoveTitle}(t) }
                        t \in Title
                \post  t \notin Title
                \end{spec}
        \end{showspecs}\noindent


% The Collection Class: LC

        \newpage \noindent

        \subsubsection*{Collection Class: \i{LC}}

        \begin{showspecs}
                \begin{spec}{ \i{LC} }
                        LT\\
                        nc : Title \to \p{NAT}\\
                        \{ InColl, ExColl \} : \p{part} \; Title\\
                        InColl := \{ t : Title \bullet nc(t) > 0 \}
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LC?showDesc}(t \to d) }
                        LT?showDesc(t \to d)
                \end{spec}
        \end{showspecs}\noindent
```


Library Lending System.tex - TeXworks
File Edit Search Format Typeset Scripts Window Help
pdfLaTeX
CRLF
UTF-8
Line 492 of 492; col 14

```
% The Catalog Class: LT

        \newpage \noindent

        \subsubsection*{Catalog Class: \i{LT}}

        \begin{showspecs}
                \begin{spec}{ \i{LT} }
                        Title: \p{set} \; \mathbb{T}\\
                        desc: Title \to \mathbb{D}
                \post  Title' = \emptyset
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT?showDesc}(t \to d) }
                        d := desc(t)
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT?showCatalog}(\to T) }
                        T := desc
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!NewTitle}(d \to t) }
                        d : \mathbb{D} \sep t : \mathbb{T} \sep t \notin Title
                \post  t \in Title' \sep desc'(t) = d
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!UpdateDesc}(t, d) }
                        t \in Title
                \post  desc'(t) = d
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LT!RemoveTitle}(t) }
                        t \in Title
                \post  t \notin Title
                \end{spec}
        \end{showspecs}\noindent


% The Collection Class: LC

        \newpage \noindent

        \subsubsection*{Collection Class: \i{LC}}

        \begin{showspecs}
                \begin{spec}{ \i{LC} }
                        LT\\
                        nc : Title \to \p{NAT}\\
                        \{ InColl, ExColl \} : \p{part} \; Title\\
                        InColl := \{ t : Title \bullet nc(t) > 0 \}
                \end{spec}
        \end{showspecs}\noindent

        \begin{showspecs}
                \begin{spec}{ \i{LC?showDesc}(t \to d) }
                        LT?showDesc(t \to d)
                \end{spec}
        \end{showspecs}\noindent
```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```
    \begin{showspecs}
        \begin{spec}{ \i{LC?showNoCopies}(t \to n) }
            n := nc(t)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LC?showInCollection}(\to C) }
            C : Title \nrightarrow \p{POS} \times \mathbb{D}\\
            C = \{ (t, n, d) : InColl \times \p{POS} \times \mathbb{D} \bullet n = nc(t) \wedge d = desc(t) \}
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LC?showOutCollection}(\to C) }
            C : Title \nrightarrow \mathbb{D}\\
            C = \{ (t, d) : ExColl \times \mathbb{D} \bullet d = desc(t) \}
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LC!NewTitle}(d, n \to t) }
            LT!NewTitle(d \to t)
        \post  nc'(t) = n
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LC!AddOrRemoveCopies}(t, n) }
            t : Title \sep n : \p{INT} \sep nc(t) + n \geq 0
        \post  nc'(t) = nc(t) + n
        \end{spec}
    \end{showspecs}\noindent



% The Loan Class: LL

    \newpage \noindent

    \subsubsection*{Loan Class: \i{LL}}

    \begin{showspecs}
        \begin{spec}{ \i{LL} }
            LM \sep LC\\
            loan : Title \nleftrightarrow Member\\
            na, nl : Title \to \p{NAT}\\
            \forall t : Title \; \bullet \\
            \ \ \ \nc(t) = na(t) + nl(t) \wedge \\
            \ \ \ \nl(t) = \# \{ m : Member \bullet t \mapsto m \in loan \}
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LL?showInfo}(m \to i) }
            LM?showInfo(m \to i)
        \end{spec}

    \showbeside
        \begin{spec}{ \i{LL?showMembers}(\to M) }
            LM?showMembers(\to M)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LL?showDesc}(t \to d) }
            LC?showDesc(t \to d)
        \end{spec}

    \showbeside
```

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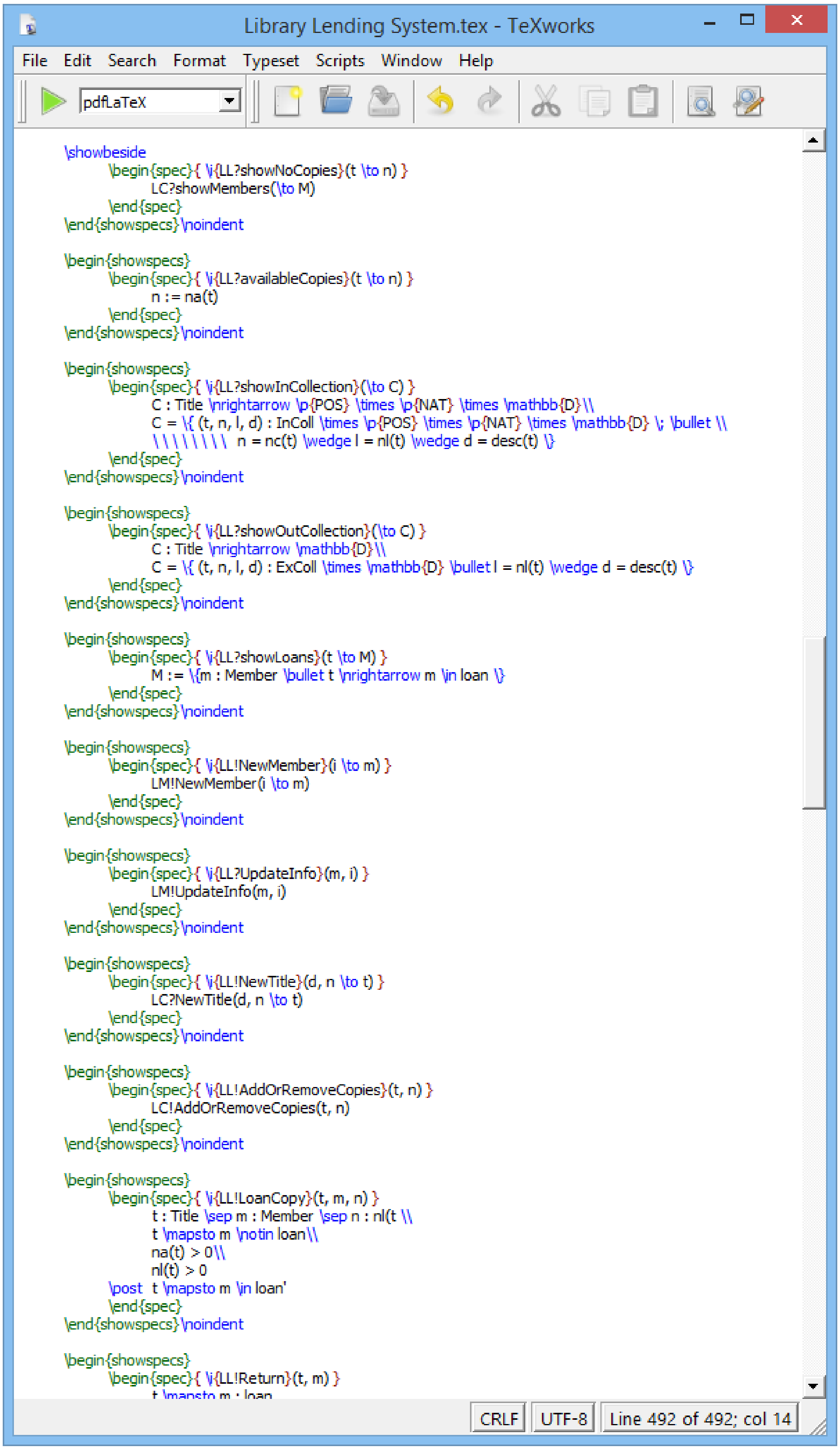
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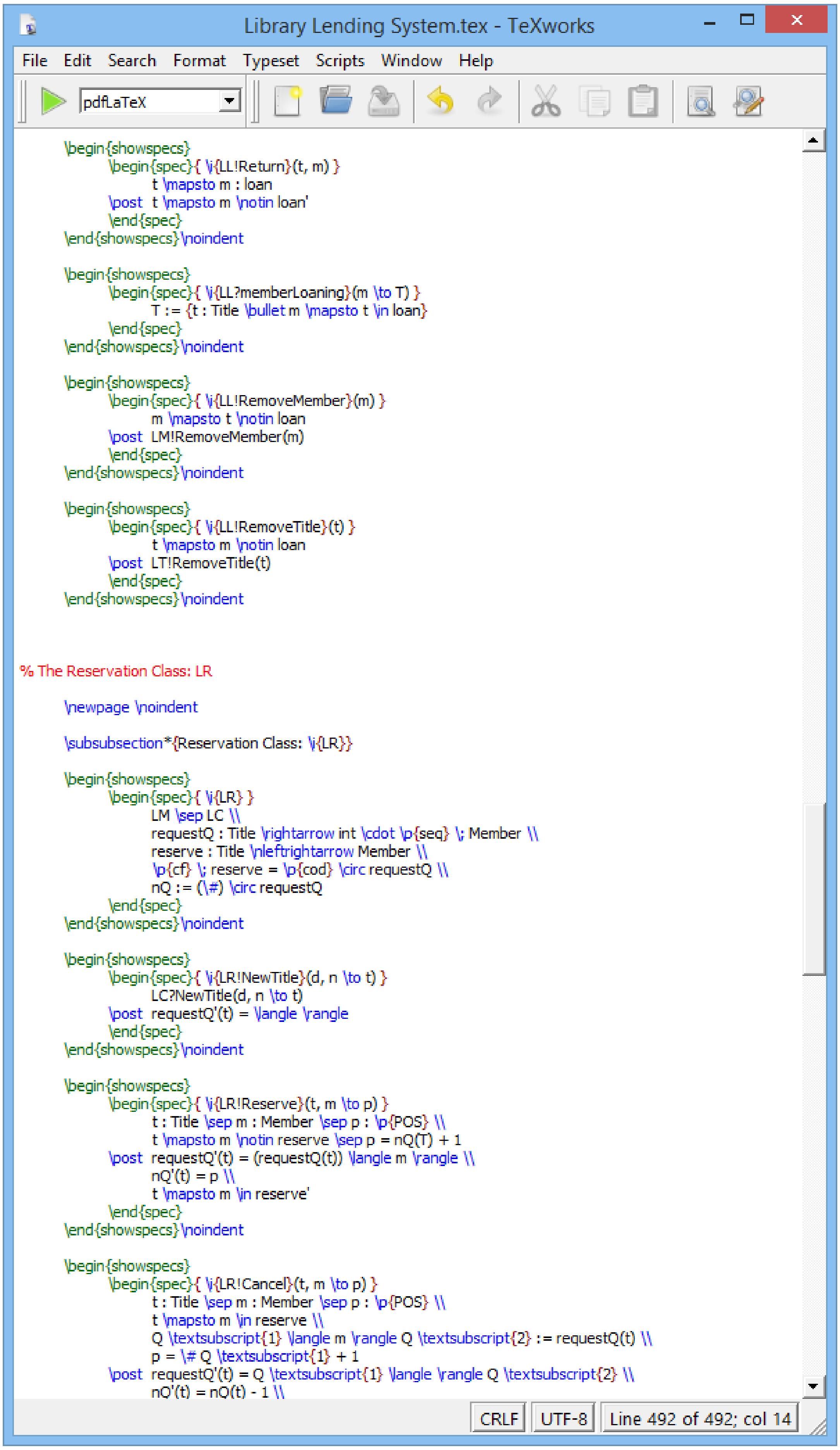
```latex
\showbeside
        \begin{spec}{ \i{LL?showNoCopies}(t \to n) }
                LC?showMembers(\to M)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL?availableCopies}(t \to n) }
                n := na(t)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL?showInCollection}(\to C) }
                C : Title \nrightarrow \p{POS} \times \p{NAT} \times \mathbb{D}\\
                C = \{ (t, n, l, d) : InColl \times \p{POS} \times \p{NAT} \times \mathbb{D} \; \bullet \\
                \ \ \ \ \ \ \ \  n = nc(t) \wedge l = nl(t) \wedge d = desc(t) \}
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL?showOutCollection}(\to C) }
                C : Title \nrightarrow \mathbb{D}\\
                C = \{ (t, n, l, d) : ExColl \times \mathbb{D} \bullet l = nl(t) \wedge d = desc(t) \}
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL?showLoans}(t \to M) }
                M := \{m : Member \bullet t \nrightarrow m \in loan \}
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL!NewMember}(i \to m) }
                LM!NewMember(i \to m)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL?UpdateInfo}(m, i) }
                LM!UpdateInfo(m, i)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL!NewTitle}(d, n \to t) }
                LC?NewTitle(d, n \to t)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL!AddOrRemoveCopies}(t, n) }
                LC!AddOrRemoveCopies(t, n)
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL!LoanCopy}(t, m, n) }
                t : Title \sep m : Member \sep n : nl(t \\
                t \mapsto m \notin loan\\
                na(t) > 0\\
                nl(t) > 0
        \post  t \mapsto m \in loan'
        \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
        \begin{spec}{ \i{LL!Return}(t, m) }
                t \mapsto m : loan
```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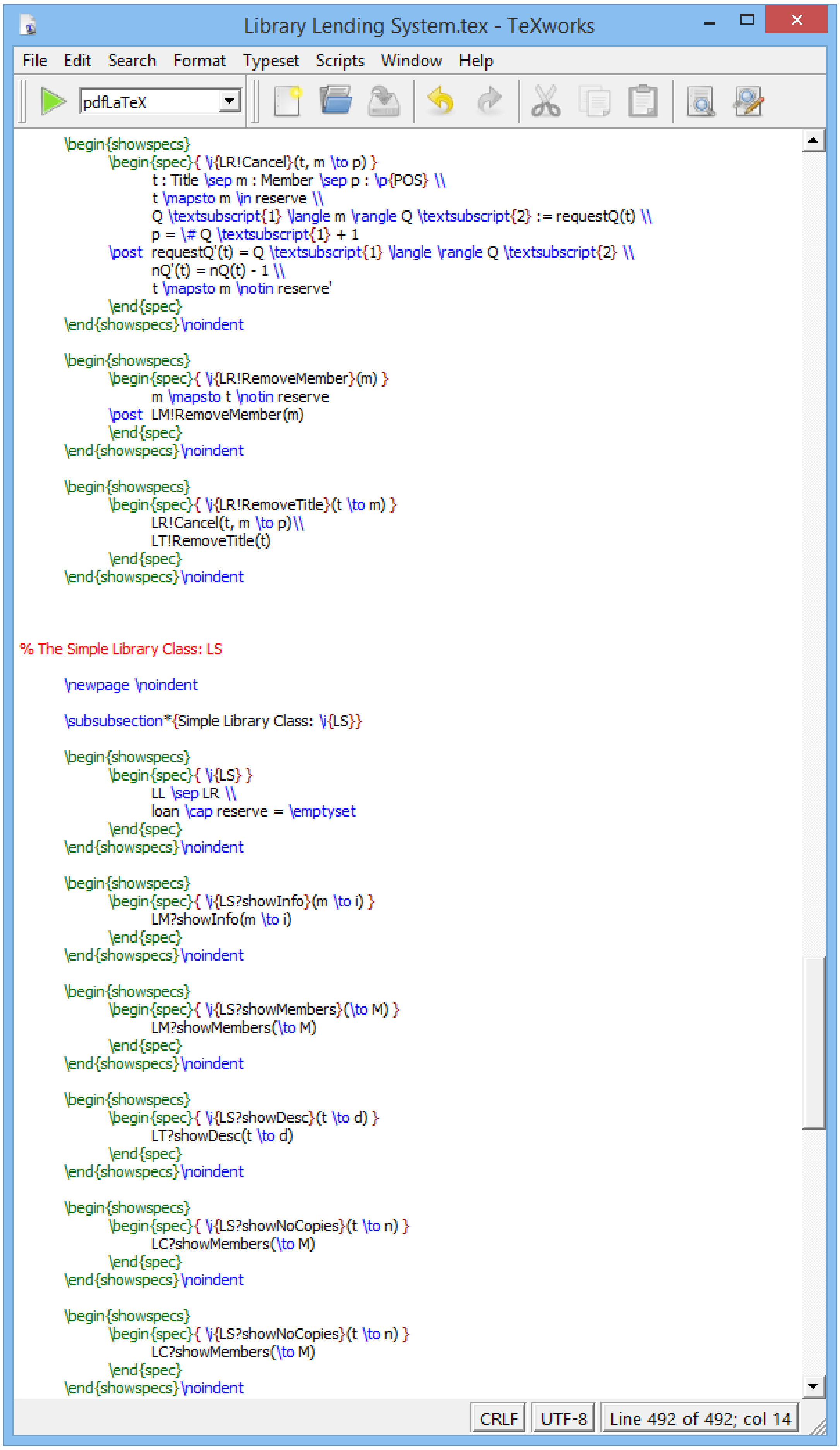
```
    \begin{showspecs}
        \begin{spec}{ \i{LL!Return}(t, m) }
            t \mapsto m : loan
        \post  t \mapsto m \notin loan'
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LL?memberLoaning}(m \to T) }
            T := {t : Title \bullet m \mapsto t \in loan}
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LL!RemoveMember}(m) }
            m \mapsto t \notin loan
        \post  LM!RemoveMember(m)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LL!RemoveTitle}(t) }
            t \mapsto m \notin loan
        \post  LT!RemoveTitle(t)
        \end{spec}
    \end{showspecs}\noindent



% The Reservation Class: LR

    \newpage \noindent

    \subsubsection*{Reservation Class: \i{LR}}

    \begin{showspecs}
        \begin{spec}{ \i{LR} }
            LM \sep LC \\
            requestQ : Title \rightarrow int \cdot \p{seq} \; Member \\
            reserve : Title \nleftrightarrow Member \\
            \p{cf} \; reserve = \p{cod} \circ requestQ \\
            nQ := (\#) \circ requestQ
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LR!NewTitle}(d, n \to t) }
            LC?NewTitle(d, n \to t)
        \post  requestQ'(t) = \langle \rangle
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LR!Reserve}(t, m \to p) }
            t : Title \sep m : Member \sep p : \p{POS} \\
            t \mapsto m \notin reserve \sep p = nQ(T) + 1
        \post  requestQ'(t) = (requestQ(t)) \langle m \rangle \\
            nQ'(t) = p \\
            t \mapsto m \in reserve'
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LR!Cancel}(t, m \to p) }
            t : Title \sep m : Member \sep p : \p{POS} \\
            t \mapsto m \in reserve \\
            Q \textsubscript{1} \langle m \rangle Q \textsubscript{2} := requestQ(t) \\
            p = \# Q \textsubscript{1} + 1
        \post  requestQ'(t) = Q \textsubscript{1} \langle \rangle Q \textsubscript{2} \\
            nQ'(t) = nQ(t) - 1 \\
```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```
    \begin{showspecs}
        \begin{spec}{ \i{LR!Cancel}(t, m \to p) }
            t : Title \sep m : Member \sep p : \p{POS} \\
            t \mapsto m \in reserve \\
            Q \textsubscript{1} \langle m \rangle Q \textsubscript{2} := requestQ(t) \\
            p = \# Q \textsubscript{1} + 1
        \post requestQ'(t) = Q \textsubscript{1} \langle \rangle Q \textsubscript{2} \\
            nQ'(t) = nQ(t) - 1 \\
            t \mapsto m \notin reserve'
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LR!RemoveMember}(m) }
            m \mapsto t \notin reserve
        \post LM!RemoveMember(m)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LR!RemoveTitle}(t \to m) }
            LR!Cancel(t, m \to p)\\
            LT!RemoveTitle(t)
        \end{spec}
    \end{showspecs}\noindent



% The Simple Library Class: LS

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    \subsubsection*{Simple Library Class: \i{LS}}

    \begin{showspecs}
        \begin{spec}{ \i{LS} }
            LL \sep LR \\
            loan \cap reserve = \emptyset
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LS?showInfo}(m \to i) }
            LM?showInfo(m \to i)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LS?showMembers}(\to M) }
            LM?showMembers(\to M)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LS?showDesc}(t \to d) }
            LT?showDesc(t \to d)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LS?showNoCopies}(t \to n) }
            LC?showMembers(\to M)
        \end{spec}
    \end{showspecs}\noindent

    \begin{showspecs}
        \begin{spec}{ \i{LS?showNoCopies}(t \to n) }
            LC?showMembers(\to M)
        \end{spec}
    \end{showspecs}\noindent
```

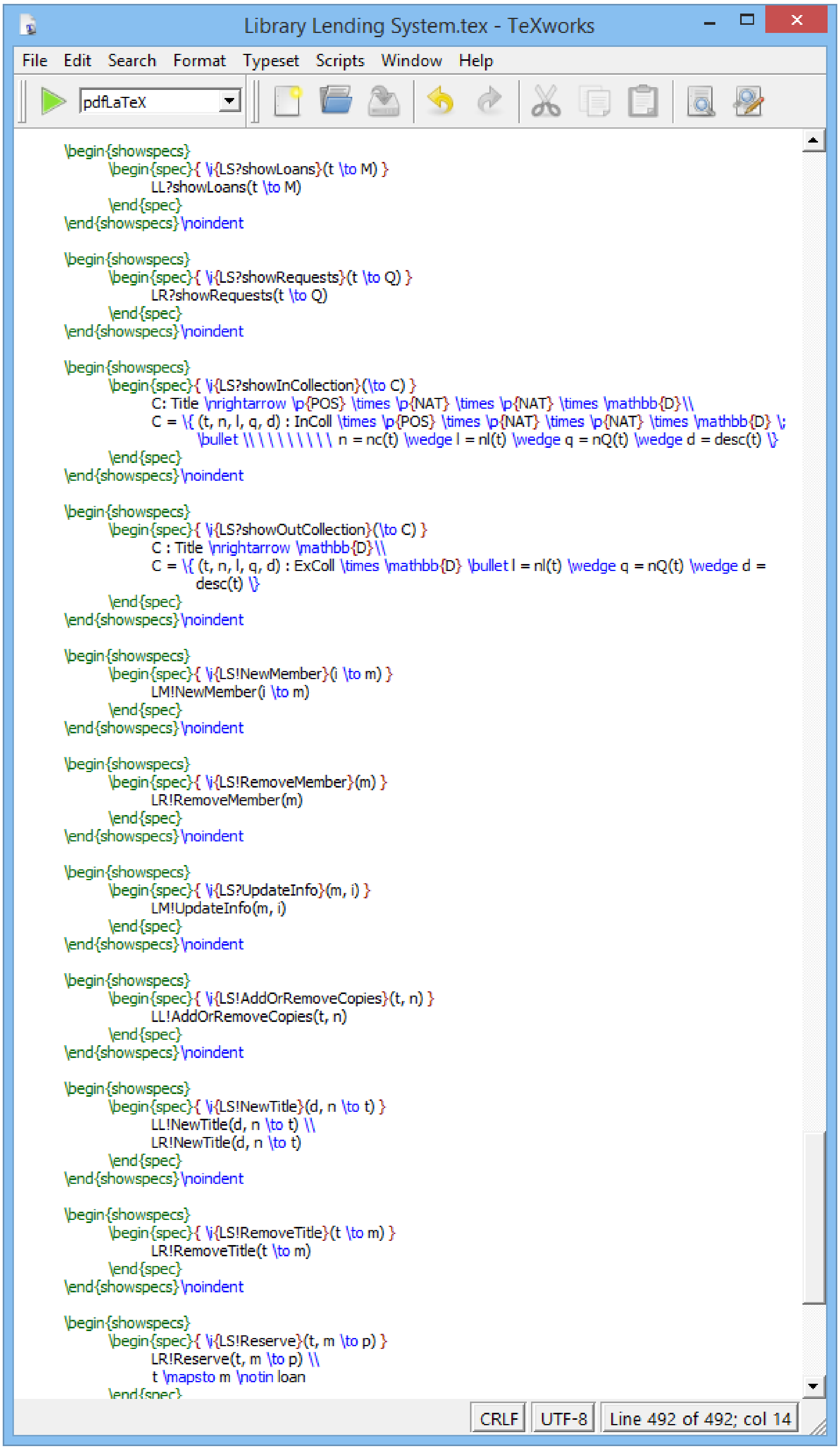
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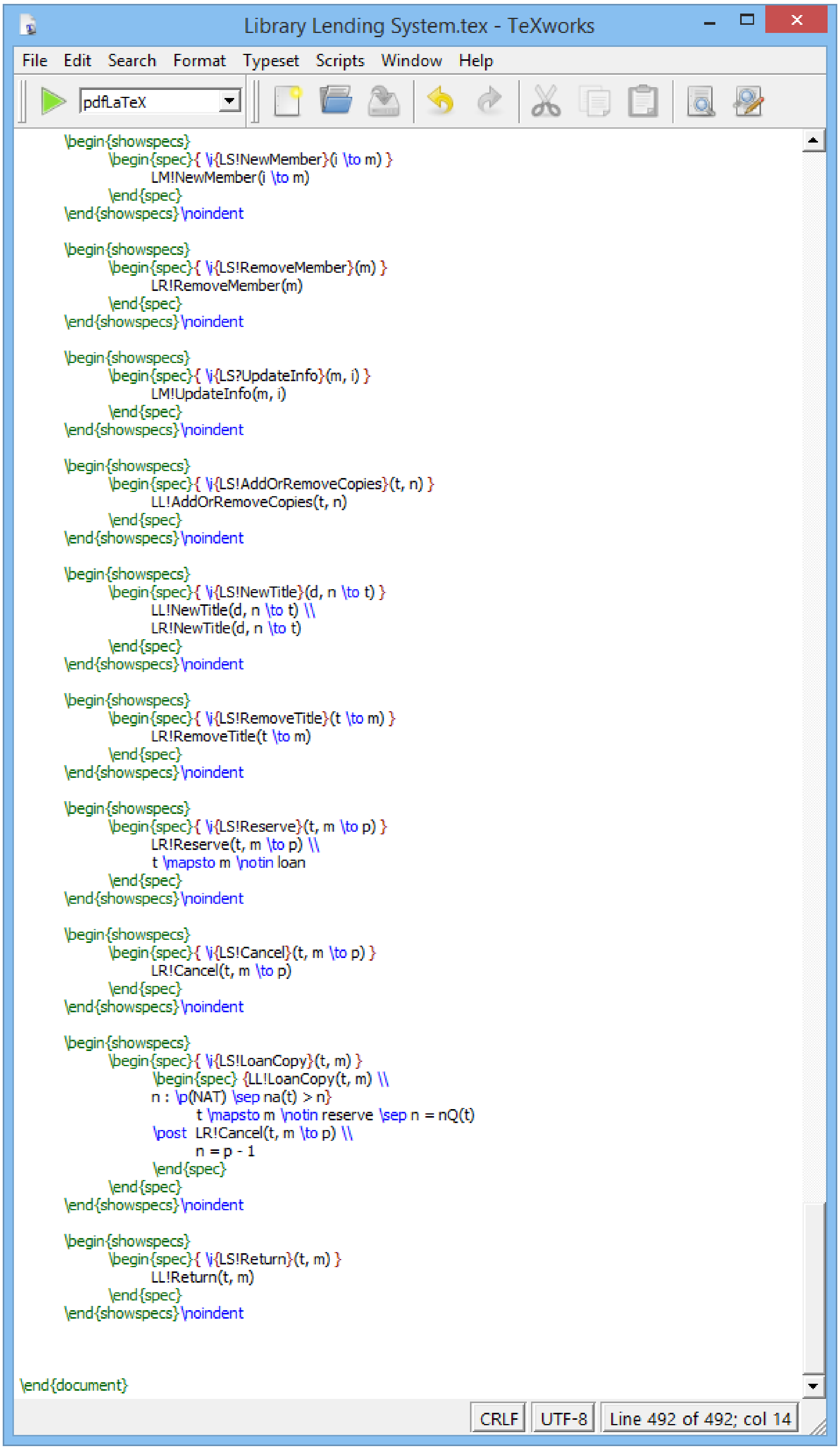
```
\begin{showspecs}
    \begin{spec}{ \i{LS?showLoans}(t \to M) }
        LL?showLoans(t \to M)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS?showRequests}(t \to Q) }
        LR?showRequests(t \to Q)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS?showInCollection}(\to C) }
        C: Title \nrightarrow \p{POS} \times \p{NAT} \times \p{NAT} \times \mathbb{D}\\
        C = \{ (t, n, l, q, d) : InColl \times \p{POS} \times \p{NAT} \times \p{NAT} \times \mathbb{D} \;
            \bullet \\ \ \ \ \ \ \ \ \ \ n = nc(t) \wedge l = nl(t) \wedge q = nQ(t) \wedge d = desc(t) \}
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS?showOutCollection}(\to C) }
        C : Title \nrightarrow \mathbb{D}\\
        C = \{ (t, n, l, q, d) : ExColl \times \mathbb{D} \bullet l = nl(t) \wedge q = nQ(t) \wedge d =
            desc(t) \}
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!NewMember}(i \to m) }
        LM!NewMember(i \to m)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!RemoveMember}(m) }
        LR!RemoveMember(m)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS?UpdateInfo}(m, i) }
        LM!UpdateInfo(m, i)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!AddOrRemoveCopies}(t, n) }
        LL!AddOrRemoveCopies(t, n)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!NewTitle}(d, n \to t) }
        LL!NewTitle(d, n \to t) \\
        LR!NewTitle(d, n \to t)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!RemoveTitle}(t \to m) }
        LR!RemoveTitle(t \to m)
    \end{spec}
\end{showspecs}\noindent

\begin{showspecs}
    \begin{spec}{ \i{LS!Reserve}(t, m \to p) }
        LR!Reserve(t, m \to p) \\
        t \mapsto m \notin loan
    \end{spec}
```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```
	\begin{showspecs}
		\begin{spec}{ \j{LS!NewMember}(i \to m) }
			LM!NewMember(i \to m)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!RemoveMember}(m) }
			LR!RemoveMember(m)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS?UpdateInfo}(m, i) }
			LM!UpdateInfo(m, i)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!AddOrRemoveCopies}(t, n) }
			LL!AddOrRemoveCopies(t, n)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!NewTitle}(d, n \to t) }
			LL!NewTitle(d, n \to t) \\
			LR!NewTitle(d, n \to t)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!RemoveTitle}(t \to m) }
			LR!RemoveTitle(t \to m)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!Reserve}(t, m \to p) }
			LR!Reserve(t, m \to p) \\
			t \mapsto m \notin loan
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!Cancel}(t, m \to p) }
			LR!Cancel(t, m \to p)
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!LoanCopy}(t, m) }
			\begin{spec} {LL!LoanCopy(t, m) \\
			n : \p(NAT) \sep na(t) > n}
				t \mapsto m \notin reserve \sep n = nQ(t)
			\post  LR!Cancel(t, m \to p) \\
				n = p - 1
			\end{spec}
		\end{spec}
	\end{showspecs}\noindent

	\begin{showspecs}
		\begin{spec}{ \j{LS!Return}(t, m) }
			LL!Return(t, m)
		\end{spec}
	\end{showspecs}\noindent


\end{document}
```