

HASKELL SYNTAX AND STATIC SEMANTICS WRITTEN IN
K-FRAMEWORK

Draft of November 26, 2018 at 03:18

BY

BRADLEY MORRELL

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Bachelor of Science in Computer Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2018

Urbana, Illinois

Adviser:

Elsa Gunter

ABSTRACT

For this thesis, I introduce a static semantics for Haskell by utilizing the K-Framework. This implementation includes support for the module system of Haskell but not for type classes. There are many layers that have to be implemented in K before type inference can be performed. The first part of the implementation is the entire context free syntax of Haskell in K. Since all the syntax is included, any program written in Haskell extended syntax can be parsed into an abstract syntax tree. However, this includes only the Haskell extended syntax but does not include the syntactic short-cuts such as treating tabs as syntactic sugar for grouping constructs such as curly braces. Programs that include multiple modules can be parsed, but the multiple modules must be written in a single file. This is unlike how the Glasgow Haskell Compiler allows for module imports, where each module must be kept in separate files. The multiple modules are then made as nodes in a directed acyclic graph. A directed edge in the graph represents a module importing another module. This graph is used for importing the user defined types from one module into another module. Context sensitive checks and type inference are then performed on modules. The static semantics specifies that, at each node in the graph, assuming all child modules are already checked and inferred, the user defined types of each of the child modules are imported into the module at the given node. All rules of the Haskell type system must take mutual recursion into account. There is repeated layering of inferences in Haskell. Due to being written in K, my semantics is mathematically precise and executable. Since the semantics is executable, the semantics can be tested against test sets to validate the correctness of the semantics. I utilized the executability of the semantics to test both positive inferences and exceptional inferences. This is part of a larger project to give a formal semantics to Haskell.

Subject Keywords: Haskell; Type-System

Draft of November 26, 2018 at 03:18

To my parents, for their love and support.

TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF ABBREVIATIONS	vii
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 CONTEXT FREE SYNTAX	3
2.1 Implementation of Section 10.2	5
2.2 Implementation of Section 10.5	8
2.3 Example Test Programs	15
CHAPTER 3 CONFIGURATION	17
CHAPTER 4 CONTEXT SENSITIVE CHECKS	19
CHAPTER 5 MULTIPLE MODULE SUPPORT	41
CHAPTER 6 INFERENCING	43
6.1 Data Structures	43
6.2 Type theory	44
6.3 Lambda Calculus	44
6.4 Hindley-Milner	44
6.5 Definition of Substitution	44
6.6 Composition of Substitutions	45
6.7 Inferencing Algorithm	45
6.8 Unification Algorithm	55
CHAPTER 7 CONCLUSION	58
APPENDIX A HASKELL-SYNTAX.K	59
APPENDIX B HASKELL-CONFIGURATION.K	71
APPENDIX C HASKELL-PREPROCESSING.K	73

Draft of November 26, 2018 at 03:18

APPENDIX D HASKELL-TYPE-INFERENCING.K	94
REFERENCES	109

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CHAPTER 1

INTRODUCTION

One of the inherent problems of engineered systems in general is that the design of the system is not proven to be working. The system could be non-functional at design time. The designer may not fully understand the system environment or may have not considered the behavior of the system in rare circumstances. Then once the design is made, there may be issues introduced by implementing the design incorrectly. Within the context of computer programs, the current way that programs are created is by making a design or a formal specification of the program, implementing it, and testing the program against unit tests or verifying the behavior of the program after the fact. Formal methods are ways to mathematically prove correctness of a system. Without formal methods, the only way to reason about a system is by testing it against different edge cases. Within the context of a programming language, one way a programming language can be formally specified is by defining a syntax and semantics for that language. The operational semantics of a programming language can be thought of as a transition system upon an abstract syntax tree, which is the program itself written in the language, and a state, which is a function from the variables in the tree to the current values of those variables. This way, real and complex programs written in natural looking programming languages can be interpreted as strings written in formal languages. Once a programming language is defined in this way, certain properties and behavior of the language and programs written in the language can be proven. K is a framework for creating the formal specification of a programming language. It then can interpret programs written in the language by running only the rules of the formal operational semantics of the programming language. This allows programs to be run and analyzed formally. This way the formal specification of the complex programming language can be tested and analyzed with the use of a machine. A K-configuration defines the memory structure of the programming language,

made up of cells. The program state can be thought of as the current values of the K-configuration at a certain point in time. Grammar can be written in K using the constructor syntax, and a semantic rule can be written in K using the constructor rule. Haskell is a purely functional programming language with strong static typing. Purely functional means that the language only allows the user to make functions whose output is only dependent on the function input. Strong static typing means that before a program is run, a type inference algorithm infers the type of the program and ensures that all functions and function applications are allowed with regards to the types of the inputs and outputs. Static refers to the fact that type inference is performed before the code is run, and will not run during the runtime of the code. Strong typing refers to the fact that the compiler will not allow the user to perform workarounds like typecasting. This project details the syntax of Haskell and the type system of Haskell in K.

CHAPTER 2

CONTEXT FREE SYNTAX

This chapter details the first part of the static semantics. In order for any context sensitive checks or type inference can be done, the test programs first need to be parsed into an abstract syntax tree. The context sensitive checks and type inference can then be performed upon the tree. Some difficulties with implementing a grammar into K is that the grammar originally is written in sort descending order in a document. The goal was to build a grammar that can parse actual programs and ensure there was no bugs. To do this, I started with small example programs, wrote out the example abstract syntax tree, and included the sorts necessary to parse them. Then if they didn't parse correctly I could then debug. I then wrote bigger and bigger example programs and included more and more sorts until all the grammar was included.

The Haskell 2010 report is the current official specification of the Haskell language. The grammar specified in section 10.5 of the Haskell 2010 report is a specification of the expanded syntax of Haskell. As specified in section 2.7, the expanded syntax of Haskell specifies Haskell programs when written using semicolons and braces. However, these can be omitted in a real Haskell program. The compiler will then utilize layout rules for certain grammar structures instead. These are specified in section 10.3 The parser for this project does not implement these layout rules and instead only can parse the expanded, layout insensitive syntax of Haskell. It would require another script to convert a program written using the layout sensitive syntax into the expanded syntax in order to parse the program. Haskell has a context free grammar. Section 10.1 specifies the notation used in the grammar. The notation of 10.1 are always in bold in the grammar. So

```
1 qvarid -> [ modid . ] varid
```

Means that

1 `modid .`

is optional, and the brackets

1 `[]`

are not part of the Haskell code, but the period

1 `.`

is part of the Haskell code. Any symbol that is not in bold needs to be written in the program in order to parse correctly. There are a lot of parts of the grammar that were tricky for me to implement in K. For instance, a sort definition with an optional part could be just written using a pipe in the K syntax.

So the example production

1 `qvarid -> [modid .] varid`

Is written in my K syntax as split into two options.

1 `syntax QVarId ::= VarId | ModId "." VarId [klabel('qVarIdCon)]`

However, an issue arises when you have something written on the right hand side of the production like

1 `data [context =>] simpletype [= constrs] [deriving]`

for the topdecl sort. If each optional sort were split into two options, then a production that includes n optional sorts would require 2^n options. This would create an unnecessarily large syntax in K.

Instead, for each optional sort in the original grammar, I replaced the optional sort with a new sort. For instance, I replaced

1 `[context =>]`

in the original grammar with a new sort called OptContext. Then I just specified

1 `syntax OptContext ::= Context ">" | "" [onlyLabel, klabel('emptyContext)]`

This is acceptable because Haskell is not an order sorted algebra, so introducing new sorts that are not originally in the grammar is okay.

In K,

```
1 [klabel('exampleLabel)]
```

means that in the abstract syntax tree created by K, a term can be referred to using that klabel in a K rule.

2.1 Implementation of Section 10.2

The following introduces the syntax for the keywords, constants, special symbols, and variables that comprise the terminals for the remaining context free grammar as presented in section 10.1 of the Haskell manual.

```
1 // Syntax from haskell 2010 Report
2 // https://www.haskell.org/onlinereport/haskell2010/haskellch10.
  html#x17-17500010
3
4 module HASKELL-SYNTAX
5
6     syntax Integer ::= Token{([0-9]+)
7         | (([0][o]|[0][O])[0-7]+)
8         | (([0][x] | [0][X])[0-9a-fA-F]+)} [onlyLabel]
9
10    syntax CusFloat ::= Token{([0-9]+[\.][0-9]+([e E
11        ][\+|-]?[0-9]+)?)
12        | ([0-9]+[e E][\+|-]?[0-9]+)} [
13        onlyLabel]
14
15    syntax CusChar ::= Token{[\'](~[\'\\&])[\']} [onlyLabel]
16    syntax CusString ::= Token{[\"](~[\"\\&]*)[\"]} [onlyLabel]
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
2227
2228
2229
2230
2231
2232
2233
2234
2235
2236
2237
2238
2239
2240
2241
2242
2243
2244
2245
2246
2247
2248
2249
2250
2251
2252
2253
2254
2255
2256
2257
2258
2259
2260
2261
2262
2263
2264
2265
2266
2267
2268
2269
2270
2271
2272
2273
2274
2275
2276
2277
2278
2279
2280
2281
2282
2283
2284
2285
2286
2287
2288
2289
2290
2291
2292
2293
2294
2295
2296
2297
2298
2299
2300
2301
2302
2303
2304
2305
2306
2307
2308
2309
2310
2311
2312
2313
2314
2315
2316
2317
2318
2319
2320
2321
2322
2323
2324
2325
2326
2327
2328
2329
2330
2331
2332
2333
2334
2335
2336
2337
2338
2339
2340
2341
2342
2343
2344
2345
2346
2347
2348
2349
2350
2351
2352
2353
2354
2355
2356
2357
2358
2359
2360
2361
2362
2363
2364
2365
2366
2367
2368
2369
2370
2371
2372
2373
2374
2375
2376
2377
2378
2379
2380
2381
2382
2383
2384
2385
2386
2387
2388
2389
2390
2391
2392
2393
2394
2395
2396
2397
2398
2399
2400
2401
2402
2403
2404
2405
2406
2407
2408
2409
2410
2411
2412
2413
2414
2415
2416
2417
2418
2419
2420
2421
2422
2423
2424
2425
2426
2427
2428
2429
2430
2431
2432
2433
2434
2435
2436
2437
2438
2439
2440
2441
2442
2443
2444
2445
2446
2447
2448
2449
2450
2451
2452
2453
2454
2455
2456
2457
2458
2459
2460
2461
2462
2463
2464
2465
2466
2467
2468
2469
2470
2471
2472
2473
2474
2475
2476
2477
2478
2479
2480
2481
2482
2483
2484
2485
2486
2487
2488
2489
2490
2491
2492
2493
2494
2495
2496
2497
2498
2499
2500
2501
2502
2503
2504
2505
2506
2507
2508
2509
2510
2511
2512
2513
2514
2515
2516
2517
2518
2519
2520
2521
2522
2523
2524
2525
2526
2527
2528
2529
2530
2531
2532
2533
2534
2535
2536
2537
2538
2539
2540
2541
2542
2543
2544
2545
2546
2547
2548
2549
2550
2551
2552
2553
2554
2555
2556
2557
2558
2559
2560
2561
2562
2563
2564
2565
2566
2567
2568
2569
2570
2571
2572
2573
2574
2575
2576
2577
2578
2579
2580
2581
2582
2583
2584
2585
2586
2587
2588
2589
2590
2591
2592
2593

```

```

5      | ([\.] [\! \# \$ \% \& \* \+ \. \< \= \> \? \@ \\\ \^ \\\ \- \~
      \:] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
6      | ([\~] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \:] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
7      | ([\@] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
8      | ([\~] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
9      | ([\|] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
10     | ([\|] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
11     | ([\:] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
12     | ([\<] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \:] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)
13     | ([\=] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \:] [\! \# \$ \% \& \* \+ \. \. \< \= \> \? \@ \\\ \^ \\\ \-
      \~ \:]*)} [onlyLabel]
14     syntax ConSym ::= Token{[\:] [\! \# \$ \% \& \* \+ \. \. \<
      \= \> \? \@ \\\ \^ \\\ \- \~] [\! \# \$ \% \& \* \+ \. \. \<
      \= \> \? \@ \\\ \^ \\\ \- \~ \:]*)} [onlyLabel]
15
16     syntax IntFloat ::= "(" Integer ")" [bracket] //NOT
      OFFICIAL SYNTAX
17     | "(" CusFloat ")" [bracket]

```

I ran into an issue where floats and integers did not parse correctly. They caused parsing errors due to ambiguity of parsing. For example the number 123.45 had ambiguity where the parser did not know if 1, 12, or 123 were integers, and if 5 was an integer, or if the entire thing was one float. Normally in K, different tokens are separated with whitespaces. However, for some reason the parser had difficulty here. Initially, I added a workaround by requiring parentheses around each integer and floating point. f y z (2) This fixed the issue.

```

1     syntax Literal ::= IntFloat | CusChar | CusString
2     syntax TyCon  ::= ConId

```

```
3      syntax ModId ::= ConId | ConId "." ModId [klabel('conModId)
      ]
4      syntax QTyCon ::= TyCon | ModId "." TyCon [klabel('conTyCon)
      ]
5      syntax QVarId ::= VarId | ModId "." VarId [klabel('qVarIdCon
      )]
6      syntax QVarSym ::= VarSym | ModId "." VarSym [klabel('
      qVarSymCon)]
7      syntax QConSym ::= ConSym | ModId "." ConSym [klabel('
      qConSymCon)]
8  /*      syntax QTyCls ::= QTyCon
9      syntax TyCls ::= ConId
10 */
11      syntax TyVars ::= List{TyVar, ""} [klabel('typeVars)] //used
      in SimpleType syntax
12      syntax TyVar ::= VarId
13      syntax TyVarTuple ::= TyVar "," TyVar [klabel('
      twoTypeVarTuple)]
14      | TyVar "," TyVarTuple [klabel('
      typeVarTupleCon)]
15
16      syntax Con ::= ConId | "(" ConSym ")" [klabel('
      conSymBracket)]
17      syntax Var ::= VarId | "(" VarSym ")" [klabel('
      varSymBracket)]
18      syntax QVar ::= QVarId | "(" QConSym ")" [klabel('
      qVarBracket)]
19      syntax QCon ::= QTyCon | "(" GConSym ")" [klabel('
      gConBracket)]
20
21      syntax QConOp ::= GConSym | "\"" QTyCon "\"" [klabel('
      qTyConQuote)]
22      syntax QVarOp ::= QVarSym | "\"" QVarId "\"" [klabel('
      qVarIdQuote)]
23      syntax VarOp ::= VarSym | "\"" VarId "\"" [klabel('
      varIdQuote)]
24      syntax ConOp ::= ConSym | "\"" ConId "\"" [klabel('
      conIdQuote)]
25
26      syntax GConSym ::= ":" | QConSym
27      syntax Vars ::= Var
28      | Var "," Vars [klabel('varCon)]
29      syntax VarsType ::= Vars "::" Type [klabel('varAssign)]
```

```
30     syntax Ops ::= Op
31                   | Op "," Ops  [klabel('opCon)]
32     syntax Fixity ::= "infixl" | "infixr" | "infix"
33     syntax Op ::= VarOp | ConOp
34     syntax CQName ::= Var | Con | QVar
35
36     /* syntax QConId ::= ConId | ModId "." ConId */
37
38     syntax QOp ::= QVarOp | QConOp
```

2.2 Implementation of Section 10.5

The following introduces the sorts of the context free grammar of the Haskell extended syntax.

We start with modules.

```
1     syntax ModuleName ::= "module" ModId [klabel('moduleName)]
2
3     syntax Module ::= ModuleName "where" Body [klabel('
4                       module)]
5                       | ModuleName Exports "where" Body [klabel('
6                           moduleExp)]
7                       | Body [klabel('
8                           moduleBody)]
9
10    syntax Body ::= "{" ImpDecls ";" TopDecls "}" [klabel('
11                      bodyimpandtop)]
12                      | "{" ImpDecls "}" [klabel('bodyimpdecls)]
13                      | "{" TopDecls "}" [klabel('bodytopdecls)]
14
15    syntax ImpDecls ::= List{ImpDecl, ";"} [klabel('impDecls)]
```

The sort that contains all the other sorts is a module. A module represents one complete Haskell program. It can have either a name and a body, a name and a body with exports, or just a body.

The following example program has a Module with only ImpDecls. It has one ImpDecl.

```
1 module Foo where
2 {import Bar
3 }
```

The following example program has a Module with no name and only ImpDecls. It has one ImpDecl.

```
1 import Bar
```

The definition of ImpDecl is the following

```
1  syntax ImpDecl ::= "import" OptQualified ModId OptAsModId
    OptImpSpec [klabel('impDecl)]
2      | "" [onlyLabel, klabel('emptyImpDecl)]
3  syntax OptQualified ::= "qualified"
4      | "" [onlyLabel, klabel('
    emptyQualified)]
5  syntax OptAsModId ::= "as" ModId
6      | "" [onlyLabel, klabel('
    emptyOptAsModId)]
7
8  syntax OptImpSpec ::= ImpSpec
9      | "" [onlyLabel, klabel('
    emptyOptImpSpec)]
10
11 syntax ImpSpecKey ::= "(" ImportList OptComma ")"
12 syntax ImpSpec ::= ImpSpecKey
13      | "hiding" ImpSpecKey
14
15 syntax ImportList ::= List{Import, ","}
16
17 syntax Import ::= Var
18      | TyCon CQList
```

An import is another module that this module depends on.

```
1  syntax TopDecls ::= List{TopDecl, ";"} [klabel('topdeclslist
    )]
2
3  syntax TopDecl ::= Decl [klabel('topdecldecl)]
4      > "type" SimpleType "=" Type [klabel('type)
    ]
5      | "data" OptContext SimpleType OptConstrs
    OptDeriving [klabel('data)]
6      | "newtype" OptContext SimpleType "="
    NewConstr OptDeriving [klabel('newtype)]
7      | "class" OptContext ConId TyVar OptCDecls
    [klabel('class)]
```

```
8           | "instance" OptContext QTyCon Inst
           | OptIDecls [klabel('instance)]
9           | "default" Types [klabel('default)]
10          | "foreign" FDecl [klabel('foreign)]
```

The main types of expressions in Haskell are TopDecls - Top Declarations. A top declaration can either be a type, a data, a newtype, a class, an instance, a default, a foreign, or an arbitrary declaration.

```
1  syntax OptDecls ::= "where" Decls | "" [onlyLabel, klabel('
    emptyOptDecls)]
2  syntax Decls ::= "{" DeclsList "}" [klabel('decls)]
3  syntax DeclsList ::= List{Decl, ";"} [klabel('declsList)]
4
5  syntax Decl ::= GenDecl
6                | FunLhs Rhs [klabel('declFunLhsRhs)]
7                | Pat Rhs [klabel('declPatRhs)]
```

Any sort that starts with 'Opt' means that this is optional. In K something can be made optional by declaring the necessary constructors or nothing.

A Decl is any general declaration. So something like

```
1 f x = x + 2
```

is a Decl.

```
1  syntax GenDecl ::= VarsType
2                | Vars ":" Context "=>" Type [klabel('
    genAssignContext)]
3                | Fixity Ops
4                | Fixity Integer Ops
5                | "" [onlyLabel, klabel('emptyGenDecl)]
6
7  syntax FunLhs ::= Var APatList [klabel('varAPatList)]
8                | Pat VarOp Pat [klabel('patVarOpPat)]
9                | "(" FunLhs ")" APatList [klabel('
    funlhsAPatList)]
10
11 syntax Rhs ::= "=" Exp OptDecls [klabel('eqExpOptDecls)]
12            | GdRhs OptDecls [klabel('gdRhsOptDecls)]
13
14 syntax GdRhs ::= Guards "=" Exp
15                | Guards "=" Exp GdRhs
16 syntax Guards ::= "|" GuardList
```

```
17     syntax GuardList ::= Guard | Guard "," GuardList [klabel('
      guardListCon)]
18     syntax Guard ::= Pat "<-" InfixExp
19                     | "let" Decls
20                     | InfixExp
21
22     //definition of exp
23     syntax Exp ::= InfixExp
24                 > InfixExp "::" Type [klabel('expAssign)]
25                 | InfixExp "::" Context "=>" Type [klabel('
      expAssignContext)]
26
27     syntax InfixExp ::= LExp
28                     > "-" InfixExp [klabel('minusInfix)]
29                     > LExp QOp InfixExp
30
31     syntax LExp ::= AExp
32                 > "\\\" APatList "->" Exp [klabel('lambdaFun)]
33                 | "let" Decls "in" Exp [klabel('letIn)]
34                 | "if" Exp OptSemicolon "then" Exp
      OptSemicolon "else" Exp [klabel('ifThenElse
      )]
35                 | "case" Exp "of" "{" Alts "}" [klabel('caseOf
      )]
36                 | "do" "{" Stmt "}" [klabel('doBlock)]
```

LExp is an important sort for the inference function. This is because LExp defines the different expression types which the inference function has specific rules for.

```
1
2     syntax OptSemicolon ::= ";" | "" [onlyLabel, klabel('
      emptySemicolon)]
3     syntax OptComma ::= "," | "" [onlyLabel, klabel('
      emptyComma)]
4
5     syntax AExp ::= QVar [klabel('aexpQVar)]
6                 | GCon [klabel('aexpGCon)]
7                 | Literal [klabel('aexpLiteral)]
8                 > AExp AExp [left, klabel('funApp)]
9                 > QCon "{" FBindList "}"
10                | AExp "{" FBindList "}" //aexp cannot be qcon
      UNFINISHED
```

```

11          //Liyi: first, does not understand the
              syntax, it is the Qcon {FBindlist}
12          //or QCon? Second, place a check in
              preprosssing.
13          //and also check the Fbindlist here
              must be at least one argument
14          > "(" Exp ")" [bracket]
15          | "(" ExpTuple ")"
16          | "[" ExpList "]"
17          | "[" Exp OptExpComma ".." OptExp "]"
18          | "[" Exp "|" Quals "]"
19          | "(" InfixExp QOp ")"
20          | "(" QOp InfixExp ")" //qop cannot be - (
              minus) UNFINISHED
21          //Liyi: place a check here to check
              if QOp is a minus

```

AExp is also an import sort for the inference function. The main parts of AExp that the inference function cares about is QVar and GCon.

```

1
2  syntax OptExpComma ::= "," Exp | "" [onlyLabel, klabel('
      emptyExpComma)]
3  syntax OptExp ::= Exp | "" [onlyLabel, klabel('emptyExp)]
4
5  syntax ExpList ::= Exp | Exp "," ExpList [right]
6  syntax ExpTuple ::= Exp "," Exp [right, klabel('
      twoExpTuple)]
7          | Exp "," ExpTuple [right, klabel('
      expTupleCon)]
8
9  //constr datatypes
10 syntax OptConstrs ::= "=" Constrs [klabel('nonemptyConstrs)
      ] | "" [onlyLabel, klabel('emptyConstrs)]
11 syntax Constrs ::= Constr [klabel('singleConstr)] |
      Constr "|" Constrs [klabel('multConstr)]
12 syntax Constr ::= Con OptBangATypes [klabel('constrCon)
      ] // (arity con = k, k 0) UNFINISHED
13          | SubConstr ConOp SubConstr
14          | Con "{" FieldDeclList "}"
15
16 syntax NewConstr ::= Con AType [klabel('newConstrCon)]
17          | Con "{" Var ":@" Type "}"
18

```

```
19  syntax SubConstr    ::= BType | "!" AType
20  syntax FieldDeclList ::= List{FieldDecl, ", "}
21  syntax FieldDecl    ::= VarsType
22                        | Vars ":@" "!" AType
23
24
25  syntax OptBangATypes ::= List{OptBangAType, " "} [klabel('
    optBangATypes)]
26  syntax OptBangAType  ::= OptBang AType [klabel('optBangAType)
    ]
27  syntax OptBang       ::= "!" | "" [onlyLabel, klabel('emptyBang)]
28
29  syntax OptContext    ::= Context "=>" | "" [onlyLabel, klabel('
    emptyContext)]
30  syntax Context       ::= Class
31                        | "(" Classes ")"
32
33  syntax Classes       ::= List{Class, ", "}
34
35  syntax SimpleClass   ::= QTyCon TyVar [klabel('classCon)]
36
37  syntax Class         ::= SimpleClass
38                        | QTyCon "(" TyVar ATypeList ")"
39                        //Liyi: a check in preprocessing to
39                        check if the Atype list is
39                        empty
40                        //it must have at least one item
41
42  //define type and simple type
43  syntax SimpleType    ::= TyCon TyVars [klabel('simpleTypeCon)
    ]
44  syntax Type          ::= BType
45                        | BType "->" Type [klabel('typeArrow)]
46  syntax BType         ::= AType
47                        | BType AType [klabel('baTypeCon)]
48
49  syntax ATypeList     ::= List{AType, ""} [klabel('atypeList)]
50
51  syntax AType         ::= GTyCon [klabel('
    atypeGTyCon)]
52                        | TyVar [klabel('
    atypeTyVar)]
53                        | "(" TypeTuple ")" [klabel('
```

```

                                atypeTuple)]
54         | "[" Type "]"                [klabel('tyList)
                                ]
55         | "(" Type ")"                [bracket]
56 syntax TypeTuple ::= Type "," Type    [right,klabel('
                                twoTypeTuple)]
57         | Type "," TypeTuple          [klabel('
                                typeTupleCon)]
58 syntax Types ::= List{Type, ","}
59
60 syntax GConCommas ::= "," | "," GConCommas
61 syntax GConCommon ::= "(" | "[]" | "(" GConCommas ")" //was
                                incorrect syntax
62 syntax GTyCon ::= QTyCon
63         | GConCommon
64         | "(->)"
65
66 syntax GCon ::= GConCommon
67         | QCon
68
69 //inst definition
70 syntax Inst ::= GTyCon
71         | "(" GTyCon TyVars ")" //TyVars must be
                                distinct UNFINISHED
72         | "(" TyVarTuple ")" //TyVars must be
                                distinct
73         | "[" TyVar "]" [klabel('tyVarList)]
74         | "(" TyVar "->" TyVar ")" //TyVars must be
                                distinct
75 //pat definition
76 syntax Pat ::= LPat QConOp Pat
77         | LPat
78
79 syntax LPat ::= APat
80         | "-" IntFloat [klabel('minusPat)]
81         | GCon APatList [klabel('lpatCon)]//arity
                                gcon = k UNFINISHED
82
83 syntax APatList ::= APat | APat APatList [klabel('apatCon)]
84
85 syntax APat ::= Var [klabel('apatVar)]
86         | Var "@" APat
87         | GCon
```

```
88             | QCon "{" FPats "}"
89             | Literal [klabel('apatLiteral)]
90             | "_"
91             | "(" Pat ")" [bracket]
92             | "(" PatTuple ")"
93             | "[" PatList "]"
94             | "~" APat
95
96 syntax PatTuple ::= Pat "," Pat [klabel('twoPatTuple
    )]
97             | Pat "," PatTuple [klabel('patTupleCon
    )]
98 syntax PatList ::= Pat
99             | Pat "," PatList [klabel('patListCon)
    ]
100
101 syntax FPats ::= List{FPat, ","}
102 syntax FPat ::= QVar "=" Pat
103
104 //definition of quals
105 syntax Quals ::= Qual | Qual "," Quals [klabel('qualCon)]
106
107 syntax Qual ::= Pat "<-" Exp
108             | "let" Decls
109             | Exp
110
111 //definition of alts
112 syntax Alts ::= Alt | Alt ";" Alts
113
114 syntax Alt ::= Pat "->" Exp [klabel('altArrow)]
115             | Pat "->" Exp "where" Decls
116             | "" [onlyLabel, klabel('emptyAlt)]
117
118 //definition of stmts
119 syntax Stmts ::= StmtList Exp OptSemicolon
120 syntax StmtList ::= List{Stmt, ""}
121 syntax Stmt ::= Exp ";"
122             | Pat "<-" Exp ";"
123             | "let" Decls ";"
124             | ";"
125
126 //definition of fbind
127 syntax FBindList ::= List{FBind, ","}
```

An example program is

The corresponding abstract syntax tree in K is

Module contains two children. The first child of module is moduleName which contains the token Simp1. Simp1 is a constructor ID because it starts with a capital letter. The second child of module is bodyimpdecls. This contains the sort impDecls which is a list of impDecls. This program has only one impDecl. Since there is no qualified, the impDecl contains the child emptyQualified, followed by the token Test. Since there is no AsModId or ImpSpec, the last two children are emptyOptAsModId and emptyOptImpSpec.

CHAPTER 3

CONFIGURATION

K is used for defining a state machine and the K rules define the transition rules for the state machine. The configuration of the state machine is made up of K cells. The K cells contain all the code and the memory of the state machine. An actual state of the state machine in K is when the cells each have some term inside of them.

The following is the configuration of my Haskell semantics.

```
1 requires "haskell-syntax.k"
2
3 module HASKELL-CONFIGURATION
4     imports HASKELL-SYNTAX
5
6     syntax KItem ::= "startImportRecursion"
7     syntax KItem ::= callInit(K)
8     //syntax KItem ::= initPreModule(K) [function]
9     //syntax KItem ::= tChecker(K) [function]
10
11     configuration
12         <T>
13         <k> $PGM:ModuleList ~> startImportRecursion </k>
14         <tempModule> .K </tempModule>
15         <tempCode> .K </tempCode>
```

The $< k >$ cell is the cell that computation takes place in. The program initially tempModule is the name of the current module.

```
1 <typeIterator> 1 </typeIterator>
```

typeIterator is used for creating a fresh type variable. It has the current count of how many fresh type variables that were created.

```
1 <tempAlpha> .K </tempAlpha>
2 <tempAlphaMap> .Map </tempAlphaMap>
```

Alpha is a map of type renamings. So if a user declares

```
1 data MyBool = TTrue
2 ;type MyBooltwo = MyBool
```

Then MyBooltwo is a renaming of MyBool. In tempAlpha, an AObject is made. An AObject is a KItem with two children. One can be thought of as a Key and the other is the Value for a map. So MyBool -j MyBooltwo. However, we want to check and reject programs that have multiple renamings, so we cannot use a K Map which has idempotence. However, once we make this check, we can then use a K Map. This is what tempAlphaMap is.

```
1      <tempBeta> .Map </tempBeta>
2      <tempT> .K </tempT>
3      <tempDelta> .Map </tempDelta>
4      <tempAlphaStar> .K </tempAlphaStar>
5      <tempBetaStar> .K </tempBetaStar>
6      <importTree> .List </importTree>
7      <recurImportTree> .List </recurImportTree>
8      <impTreeVMap> .Map </impTreeVMap>
9      <modules> //static information about a module
10         <module multiplicity="*">
11             <moduleName> .K </moduleName>
12             <moduleAlphaStar> .K </moduleAlphaStar>
13             <moduleBetaStar> .K </moduleBetaStar>
14             <moduleImpAlphas> .List </moduleImpAlphas>
15             <moduleImpBetas> .List </moduleImpBetas>
16             <moduleCompCode> .K </moduleCompCode>
17             <moduleTempCode> .K </moduleTempCode>
18             <imports> .Set </imports>
19             <classes> //static information about a
                module
20                 <class multiplicity="*">
21                     <className> .K </className>
22                 </class>
23             </classes>
24         </module>
25     </modules>
26 </T>
27
28 endmodule
```

CHAPTER 4

CONTEXT SENSITIVE CHECKS

I also placed the user defined types into data structures in order to perform several checks to make sure that the user did not have errors when creating types. Then the data structures will be transformed into a form that will be used for type inferencing. Section 4 of the Haskell 2010 report specifies the haskell type system. In the topdecl sort, there are three typecons that are used to create user defined datatypes. Data, type, and newtype. The end goal is to put the user defined types into a data structure which I can use to perform type inferencing. These three typecons are used to create user defined types. The first one is type,

```
1 type simpletype = type
```

This is used in a haskell program to declare a new type as a single type. In effect, it renames the type where both names now can be used to refer to the type.

```
1 type Username = String
```

Is one such example usage of type, it creates a new type Username, which is defined as just a string. Now the programmer can refer to Username or String to make a string. The second one is data,

```
1 data [context =>] simpletype [= constrs] [deriving]
```

This allows a user to declare a new type that may include many fields, and polymorphic types. For instance:

```
1 data Date = Date Int Int Int
```

This is a new type that includes the typecon Date followed by three integers.

```
1 data Poly a = Number a
```

This is a new polymorphic type with polymorphic parameter a, that has the typecon Number. The third one is newtype,

```
1 newtype [context =>] simpletype = newconstr [deriving]
```

This is very similar to data except it only parses when the newtype has only one typecon and one field.

I perform several checks here, 1. The programmer should not be able to make two user defined datatypes with the same name, even if one is created using data and another is created using type for instance. 2. The programmer should not be able to use the same typecons when making different options for their types or use the same typecons for different types. 3. There should be no cycles in type renaming using type, and the type renaming chains using type should terminate with a type defined with data or newtype. 4. The argument sorts for types defined using data or newtype should be types that exist. 5. The polymorphic parameters that appear on the right hand side of a data declaration need to appear on the left hand side as well. 6. The polymorphic parameters that appear on the left hand side of a data declaration need to be unique. I implemented a map, called alpha, of new type names as the keys and their declared types as the entries. I then collected all appearances of the typecon type in the program, and put simpletype -> type in the alpha map. However, one of the things I needed to check for in the program was whether a user declared multiple definitions with type, so I could not use a map in K because they only allow unique keys with unique entries. So I initially used a set of tuples, and then changed it to a map after checking for multiple type declarations.

The second data structure I made is called T. T holds the user defined types created using data and newtype.

```
1 syntax KItem ::= TList(K)
2 //list of T objects for every new type introduced by data and
   newtype
3 syntax KItem ::= TObjct(K,K,K)
4 //(type name, entire list of poly type vars, list of inner T
   pieces)
5 syntax KItem ::= InnerTPiece(K,K,K,K,K)
6 //(type constructor, poly type vars, argument sorts, entire
   constr block, type name)
```

T is a list of TObjects, each TObjct represents a single user defined datatype. It holds the name, the list of polymorphic parameters, and a list of inner T pieces. An inner T piece represents an option of what a type could be. It

consists of a type constructor, a list of polymorphic parameters required for this option, the fields for this option, the entire subtree of the AST for this option unedited, and the type name again. I then used these data structures to perform these checks, and afterwards will transform them into a new data structure to perform type inferencing.

```
1 //
2 requires "haskell-syntax.k"
3 requires "haskell-configuration.k"
4
5 module HASKELL-PREPROCESSING
6     imports HASKELL-SYNTAX
7     imports HASKELL-CONFIGURATION
8
9     //USER DEFINED LIST
10    //definition of ElemList
11
12    //syntax KItem ::= ElemList
13    syntax ElemList ::= List{Element, ","} [strict]
14 //    syntax Int ::= lengthOfList (ElemList) [function]
15
16 //    rule lengthOfList (.ElemList) => 0
17 //    rule lengthOfList (val (K:K), L:ElemList) => 1 +Int
18 //    rule lengthOfList (valValue (K:K), L:ElemList) => 1 +Int
19 //    lengthOfList (L)
20
21    syntax Element ::= val (K) [strict]
22    syntax ElementResult ::= valValue (K)
23    syntax Element ::= ElementResult
24    syntax KResult ::= ElementResult
25    rule val (K:KResult) => valValue (K) [structural]
26
27    //form ElemList
28    //syntax ElemList ::= formElemList (K) [function]
29
30    //CONVERT ~> TO List
31    //list convert
32    //syntax List ::= convertToList (K) [function]
33    //rule convertToList (.K) => .List
34    //rule convertToList (A:KItem ~> B:K) => ListItem (A)
35    convertToList (B)
```

```
35
36   syntax KItem ::= dealWithImports(K,K)
37
38   rule <k> 'modListSingle('module(A:K,, B:K)) =>
      dealWithImports(A,B) ...</k>
39
40   (.Bag =>
41       <module>...    //DOT DOT DOT MEANS OVERWRITE ONLY SOME
      OF THE DEFAULTS
42       <moduleName> A </moduleName>
43       ...</module>
44   )
45
46   rule <k> 'modList('module(A:K,, B:K),, C:K) =>
      dealWithImports(A,B) ~> C ...</k>
47
48   (.Bag =>
49       <module>...    //DOT DOT DOT MEANS OVERWRITE ONLY SOME
      OF THE DEFAULTS
50       <moduleName> A </moduleName>
51       ...</module>
52   )
53
54 //   rule dealWithImports(Mod:K, A:K) => callInit(A)
55
56 //   rule <k> dealWithImports(Mod:K, A:K) => callInit(A) ...</k>
57   >
58   rule <k> dealWithImports(Mod:K, 'bodyimpandtop(A:K,, B:K))
      => .K ...</k>
59   <importTree> L:List => L importListConvert(Mod, A) </
      importTree>
60   <recurImportTree> L:List => L importListConvert(Mod, A)
      </recurImportTree>
61
62   <moduleName> Mod </moduleName>
63   <imports> S:Set (.Set => SetItem(A)) </imports>
64   <moduleTempCode> OldTemp:K => B </moduleTempCode>
65
66   rule <k> dealWithImports(Mod:K, 'bodyimpdecls(A:K)) => .K
      ...</k>
67   <importTree> L:List => L importListConvert(Mod, A) </
      importTree>
```

```
68         <recurImportTree> L:List => L importListConvert (Mod, A)
69         </recurImportTree>
70
71         <moduleName> Mod </moduleName>
72         <imports> S:Set (.Set => SetItem(A)) </imports>
73
74 //      rule <k> dealWithImports (Mod:K, 'bodytopdecls (A:K)) =>
75         callInit (A) ...</k>
76
77 rule <k> dealWithImports (Mod:K, 'bodytopdecls (B:K)) => .K
78         ...</k>
79
80 <moduleName> Mod </moduleName>
81 <moduleTempCode> OldTemp:K => B </moduleTempCode>
82
83 //importlist convert
84 syntax List ::= importListConvert (K,K) [function]
85 syntax KItem ::= impObject (K,K)
86
87 rule importListConvert (Name:K, 'impDecls (A:K,, Rest:K)) =>
88         importListConvert (Name, A) importListConvert (Name, Rest)
89
90 rule importListConvert ('moduleName (Name:K), 'impDecl (A:K,,
91         Modid:K,, C:K,, D:K)) => ListItem (impObject (Name, Modid))
92
93 rule importListConvert (Name:K, .ImpDecls) => .List
94
95 //////////////////////////////////////
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
```

```
102      ~> (checkNoNormalBlocksHavingLandingpad(.K, TNS
103          -Set TES)
104      ~> (checkAllExpBlocksHavingLandingpad(.K, TES)
105      ~> (checkAllExpInFromInvoke(.K, TES)
106      ~> (checkLandingpad
107      ~> checkLandingDomResumes)))))) ...</k> */
108
109 rule <k> startImportRecursion => checkImportCycle
110
111     ~> (recurseImportTree)...</
112         k>
113
114 syntax KItem ::= cycleCheck(K,Map,List,List) [function] //
115     current node, map of all nodes to visited or not, stack,
116     graph
117
118 syntax Map ::= createVisitMap(List,Map) [function] //graph,
119     visitmap
120
121 syntax KItem ::= getUnvisitedNode(K,K, Map) [function] //
122     visitmap
123
124 syntax List ::= getNodeNeighbors(K,List) [function] //
125     visitmap
126
127
128 rule <k> checkImportCycle
129     => cycleCheck(.K,createVisitMap(I, .Map),.List,I)
130     ...</k>
131
132 <importTree> I:List </importTree>
133
134 <impTreeVMap> .Map => createVisitMap(I, .Map) </
135     impTreeVMap>
136
137
138 syntax KItem ::= "visited"
139
140 syntax KItem ::= "unvisited"
141
142 syntax KItem ::= "none"
143
144
145 rule createVisitMap(ListItem(impObject(A:K,B:K)) Rest:List,
146     M:Map)
147
148     => createVisitMap(Rest, M[A <- unvisited][B <-
149         unvisited])
150
151 rule createVisitMap(.List, M:Map) => M
152
153
154 rule getUnvisitedNode(.K, .K, .Map) => none
155
156 rule getUnvisitedNode(.K, .K, (A:K |-> B:K) M:Map)
157
158     => getUnvisitedNode(A, B, M)
159
160 rule getUnvisitedNode(A:KItem, unvisited, M:Map) => A
161
162 rule getUnvisitedNode(A:KItem, visited, M:Map)
```



```
134         => getUnvisitedNode(.K, .K, M)
135
136
137
138     rule getNodeNeighbors(Node:K, .List) => .List
139     rule getNodeNeighbors(.K, Rest:List) => .List
140
141     rule getNodeNeighbors(Node:KItem, ListItem(impObject(Node, B:
142         KItem)) Rest:List) => getNodeNeighbors(Node, Rest)
143         ListItem(B)
144
145     rule getNodeNeighbors(Node:KItem, ListItem(impObject(A:KItem,
146         B:KItem)) Rest:List) => getNodeNeighbors(Node, Rest)
147         requires Node !=K A
148
149
150     rule cycleCheck(none, M:Map, .List, L:List) => .K
151     rule cycleCheck(.K, M:Map, .List, I:List) => cycleCheck(
152         getUnvisitedNode(.K, .K, M), M, .List, I)
153     rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:List)
154         => cycleCheck(Node, M, S, I)
155     rule cycleCheck(Node:K, M:Map, S:List, I:List)
156         => cycleCheck(.K, M[Node <- visited],
157             getNodeNeighbors(Node, I) S, I)
158         requires Node !=K .K and Bool Node !=K none
159     rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:K) =>
160         cycleCheck(Node, M, S, I)
161         requires S !=K .List
162
163     /*
164     rule cycleCheck(A:K, .K, .K, I:K) => cycleCheck(A,
165         createVisitMap(I, .Map), .List, I)
166
167
168
169
170     rule cycleCheck(Node:K, M:Map, S:List, I:K) => cycleCheck(.K
171         , M[Node <- visited], getNodeNeighbors(Node, I) S, I)
172
173
174     rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:K) =>
175         cycleCheck(Node, M, S, I)
176     //rule cycleCheck(.K, M:Map, .K, ListItem(impObject(A:K, B:K)
177         ) Rest:List) => cycleCheck(ListItem(impObject(A:K, B:K))
178         Rest:List)
179
180     */
```

165

166 //

167

168 //COPY IMPORT GRAPH, NEED SECOND GRAPH FOR RECURSING, ADDITIONAL
GRAPH FOR SELECTING IMPORTS FOR ALPHA* AND BETA*

169 //DFS for leaf

170 //acquire alpha and beta for leaf

171 //merge alpha and beta with imports to produce alpha* and beta*

172 //perform checks

173 //perform inferencing

174 //insert alpha* and beta* into importing modules

175 //remove all edges pointing to leaf

176

177 syntax KItem ::= "leafDFS"

178 syntax KItem ::= "getAlphaAndBeta"

179 syntax KItem ::= "getAlphaBetaStar"

180 syntax KItem ::= "performIndividualChecks"

181 syntax KItem ::= "performIndividualInferencing"

182 syntax KItem ::= "insertAlphaBetaStar"

183 syntax KItem ::= "removeAllEdges"

184 syntax KItem ::= "seeIfFinished"

185

186 rule <k> recurseImportTree => leafDFS

187 ~> (getAlphaAndBeta

188 //~> (getAlphaBetaStar

189 ~> (

performIndividualInferencing

))...</k>

190

191 //rule <k> dealWithImports (Mod:K, 'bodytopdecls (A:K)) =>

callInit (A) ...</k>

192

193 // rule <k> leaf

194 // => cycleCheck(.K,createVisitMap(I, .Map),.List,I)

...</k>

195 // <importTree> I:List </importTree>

196

197 //

198

199 syntax KItem ::= returnLeafDFS(K,List,Map) [function] //

current node, map of all nodes to visited or not, stack,

```

graph
200   syntax KItem ::= innerLeafDFS(K,List) [function]
201   syntax KItem ::= loadModule(K)
202
203   rule <k> leafDFS
204       => returnLeafDFS(.K,I,M) ...</k>
205       <recurImportTree> I:List </recurImportTree>
206       <impTreeVMap> M:Map </impTreeVMap>
207
208   rule returnLeafDFS(.K,ListItem(impObject(Node:KItem,B:KItem)
209       ) I:List,M:Map) => returnLeafDFS(B,I,M)
210   rule returnLeafDFS(Node:KItem,I:List,M:Map) => returnLeafDFS
211       (innerLeafDFS(Node,I),I,M)
212       requires innerLeafDFS(Node,I) !=K none
213   rule returnLeafDFS(Node:KItem,I:List,M:Map) => loadModule(
214       Node)
215       requires innerLeafDFS(Node,I) ==K none
216
217   rule innerLeafDFS(Node:KItem,ListItem(impObject(Node,B:KItem
218       )) I:List) => B
219   rule innerLeafDFS(Node:KItem,ListItem(impObject(A:KItem,B:
220       KItem)) I:List) => innerLeafDFS(Node,I)
221       requires Node !=K A
222   rule innerLeafDFS(Node:KItem,.List) => none
223 //   returnLeafDFS(Node:KItem,ListItem(impObject(Node,B:KItem))
224 //       I:List,M:Map) => returnLeafDFS(B,I,M)
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000

```

235

236

237 //

238 //get alpha and beta

239 syntax KItem ::= Module(K, K)

240 syntax KItem ::= preModule(K,K) //(alpha, T)

241

242 // STEP 1 CONSTRUCT T AND ALPHA

243 // alpha = type

244 // T = newtype and data, temporary data structure

245

246 syntax KItem ::= initPreModule(K) [function]

247 syntax KItem ::= getPreModule(K, K) [function] //(Current
term, premodule)

248 syntax KItem ::= makeT (K,K,K,K)

249

250 syntax KItem ::= fetchTypes (K,K,K,K)

251

252 syntax List ::= makeInnerT (K,K,K) [function] //LIST

253 syntax List ::= getTypeVars(K) [function] //LIST

254

255 syntax KItem ::= getCon(K) [function]

256 syntax List ::= getArgSorts(K) [function] //LIST

257

258 syntax KItem ::= AList(K)

259 syntax KItem ::= AObject(K,K) //(1st -> 2nd) map without
idempotency

260 syntax KItem ::= ModPlusType(K,K)

261

262 syntax KItem ::= TList(K) //list of T objects for every new
type introduced by data and newtype

263 syntax KItem ::= TObject(K,K,K,K) //(module name, type name,
entire list of poly type vars, list of inner T pieces)

264 syntax KItem ::= InnerTPiece(K,K,K,K,K) //(type constructor,
poly type vars, argument sorts, entire constr block,
type name)

265

266 // rule initPreModule('module(I:ModuleName,, J:K)) =>
getPreModule(J,preModule(AList(.List),TList(.List)))

267 // rule initPreModule('moduleExp(I:ModuleName,, L:K,, J:K))
=> getPreModule(J,preModule(AList(.List),TList(.List)))

```
268 //      rule initPreModule('moduleBody(J:Body)) => getPreModule(J,
      preModule(AList(.List), TList(.List)))
269
270      rule initPreModule(J:K) => getPreModule(J, preModule(AList(.
      List), TList(.List)))
271
272      rule getPreModule('bodytopdecls(I:K), J:K) => getPreModule(I
      , J)
273      rule getPreModule('topdeclslist('type(A:K,, B:K),, Rest:K), J
      :K) => fetchTypes(A,B,Rest,J) //constructalpha
274
275
276      rule getPreModule('topdeclslist('data(A:K,, B:K,, C:K,, D:K)
      ,, Rest:K), J:K) => makeT(B,C,Rest,J)
277      rule getPreModule('topdeclslist('newtype(A:K,, B:K,, C:K,, D
      :K),, Rest:K), J:K) => makeT(B,C,Rest,J)
278
279
280      rule getPreModule('topdeclslist('topdecldecl(A:K),, Rest:K),
      J:K) => getPreModule(Rest,J)
281      rule getPreModule('topdeclslist('class(A:K,, B:K,, C:K,, D:K
      ),, Rest:K), J:K) => getPreModule(Rest,J)
282      rule getPreModule('topdeclslist('instance(A:K,, B:K,, C:K,,
      D:K),, Rest:K), J:K) => getPreModule(Rest,J)
283      rule getPreModule('topdeclslist('default(A:K,, B:K,, C:K,, D
      :K),, Rest:K), J:K) => getPreModule(Rest,J)
284      rule getPreModule('topdeclslist('foreign(A:K,, B:K,, C:K,, D
      :K),, Rest:K), J:K) => getPreModule(Rest,J)
285      rule getPreModule(.TopDecls, J:K) => J
286
287      //rule getPreModule('module(I:ModuleName, L:K, J:K)) =>
      preModule(J)
288
289      rule <k> fetchTypes('simpleTypeCon(I:TyCon,, H:TyVars), '
      atypeGTyCon(C:K), Rest:K, preModule(AList(M:List), L:K))
      => getPreModule(Rest, preModule(AList(ListItem(AObject(
      ModPlusType(ModName,I),C)) M), L)) ...</k>
290      <tempModule> ModName:KItem </tempModule>
291
292      rule <k> makeT('simpleTypeCon(I:TyCon,, H:TyVars), D:K, Rest
      :K, preModule(AList(M:List), TList(ListInside:List))) =>
      getPreModule(Rest, preModule(AList(M), TList(ListItem(
      TObject(ModName,I,H,makeInnerT(I,H,D))) ListInside)))
```

```

...</k>
293     <tempModule> ModName:KItem </tempModule>
294
295     rule makeInnerT(A:K,B:K,'nonemptyConstrs(C:K)) => makeInnerT
      (A,B,C)
296     rule makeInnerT(A:K,B:K,'singleConstr(C:K)) => ListItem(
      InnerTPiece(getCon(C),getTypeVars(C),getArgSorts(C),C,A))
297     rule makeInnerT(A:K,B:K,'multConstr(C:K,, D:K)) => ListItem(
      InnerTPiece(getCon(C),getTypeVars(C),getArgSorts(C),C,A))
      makeInnerT(A,B,D)
298
299     rule getTypeVars('constrCon(A:K,, B:K)) => getTypeVars(B)
300     rule getTypeVars('optBangATypes(A:K,, Rest:K)) =>
      getTypeVars(A) getTypeVars(Rest)
301     rule getTypeVars('optBangAType('emptyBang(.KList),, Rest:K))
      => getTypeVars(Rest)
302     rule getTypeVars('atypeGTyCon(A:K)) => .List
303     rule getTypeVars('atypeTyVar(A:K)) => ListItem(A)
304     rule getTypeVars(.OptBangATypes) => .List
305
306     //rule getCon('emptyConstrs()) => .K
307     //rule getCon('nonemptyConstrs(A:K)) => getCon(A)
308     rule getCon('constrCon(A:K,, B:K)) => A
309
310     //rule getArgSorts('constrCon(A:K,, B:K)) => B
311     rule getArgSorts('constrCon(A:K,, B:K)) => getArgSorts(B)
312     rule getArgSorts('optBangATypes(A:K,, Rest:K)) =>
      getArgSorts(A) getArgSorts(Rest)
313     rule getArgSorts('optBangAType('emptyBang(.KList),, Rest:K))
      => getArgSorts(Rest)
314     rule getArgSorts('atypeGTyCon(A:K)) => ListItem(A)
315     rule getArgSorts('atypeTyVar(A:K)) => .List
316     rule getArgSorts(.OptBangATypes) => .List
317
318     //////////////////////////////////////
319
320     rule <k> preModule(A:K,T:K) => startTTransform ...</k>
321         <tempAlpha> OldAlpha:K => A </tempAlpha>
322         <tempT> OldT:K => T </tempT>
323
324     //////////////////////////////////////

```

```
325
326 // STEP 2 PERFORM CHECKS
327
328 syntax KItem ::= "error"
329
330 syntax KItem ::= "startChecks"
331 syntax KItem ::= "checkNoSameKey"
332 //Keys of alpha and keys of T should be unique
333 syntax KItem ::= "checkTypeConsDontCollide"
334 //Make sure typeconstructors do not collide in T
335 syntax KItem ::= "makeAlphaMap"
336 //make map for alpha
337 syntax KItem ::= "checkAlphaNoLoops"
338 //alpha check for no loops
339 //check alpha to make sure that everything points to a T
340 syntax KItem ::= "checkArgSortsAreTargets"
341 //Make sure argument sorts [U] [W,V] are in the set
//      of keys of alpha and targets of T, (keys of T)
342 syntax KItem ::= "checkParUsed"
343 //NEED TO CHECK all the polymorphic parameters from right appear
//      on left. RIGHT SIDE ONLY
344 //NEED TO CHECK UNIQUENESS FOR POLY PARAM ON LEFT SIDE ONLY
345
346 //      rule <k> preModule(A:K,T:K) => startChecks ...</k>
347 //      <tempAlpha> OldAlpha:K => A </tempAlpha>
348 //      <tempT> OldT:K => T </tempT>
349
350
351 /*      rule <k> performNextChecks
352          => checkUseVars
353          ~> (checkLabelUses
354          ~> (checkBlockAddress(.K)
355          ~> (checkNoNormalBlocksHavingLandingpad(.K, TNS
//              -Set TES)
356          ~> (checkAllExpBlocksHavingLandingpad(.K, TES)
357          ~> (checkAllExpInFromInvoke(.K, TES)
358          ~> (checkLandingpad
359          ~> checkLandingDomResumes)))))) ...</k> */
360
361 rule <k> startChecks
362     => checkNoSameKey
363     ~> (checkTypeConsDontCollide
364     ~> (makeAlphaMap
```

```

365         ~> (checkAlphaNoLoops
366         ~> (checkArgSortsAreTargets
367         ~> (checkParUsed)))) ...</k>
368
369     rule <k> checkTypeConsDontCollide
370         => tyConCollCheck(T,.List,.Set) ...</k>
371     <tempT> T:K </tempT>
372
373     //syntax KItem ::= tChecker(K) [function]
374     syntax KItem ::= tyConCollCheck(K,K,K) [function] //(TList,
        List of Tycons,Set of Tycons)
375     syntax KItem ::= lengthCheck(K,K) [function]
376     //syntax KItem ::= tyConCollCheck(K,K,K) [function]
377     //syntax K ::= innerCollCheck(K) [function]
378     //syntax K ::= tyConCollCheckPasser(K, K) [function]
379
380     //rule tChecker(preModule(Alpha:Map,T:K,Mod:K)) =>
        tyConCollCheck(innerCollCheck(T),preModule(Alpha,T,Mod))
381
382     //rule tyConCollCheck(.K,preModule(Alpha:Map,H:K,Mod:K)) =>
        tyConCollCheck(innerCollCheck(H),preModule(Alpha,H,Mod))
383
384     rule tyConCollCheck(TList(ListItem(TObject(ModName:K, A:K,B:
        K,ListItem(InnerTPiece(Ty:K,E:K,F:K,H:K,G:K)) Inners:List
        )) Rest:List),J:List,D:Set) =>
385         tyConCollCheck(TList(ListItem(TObject(
            ModName,A,B,Inners)) Rest),ListItem(Ty) J
            , SetItem(Ty) D)
386     rule tyConCollCheck(TList(ListItem(TObject(ModName:K, A:K,B:
        K,.List)) Rest:List),J:List,D:Set) =>
387         tyConCollCheck(TList(Rest),J,D)
388     rule tyConCollCheck(TList(.List),J:List,D:Set) =>
389         lengthCheck(size(J),size(D))
390
391     rule lengthCheck(A:Int, B:Int) => .K
392         requires A ==Int B
393
394     rule lengthCheck(A:Int, B:Int) => error
395         requires A /=Int B
396
397     //rule tyConCollCheck(TList(TObject(A:K,B:K,C:K) ~> Rest:K),
        J:K) => tyConCollCheckPasser(TList(innerCollCheck(TObject
        (A:K,B:K,C:K)) ~> Rest:K),J:K)

```



```
398     syntax KItem ::= keyCheck(K,K,K,K) [function] //(Alpha, T,
        List of names, Set of names)
399
400     rule <k> checkNoSameKey
401         => keyCheck(A, T, .Set, .List) ...</k>
402         <tempAlpha> A:K </tempAlpha>
403         <tempT> T:K </tempT>
404     //rule <k> checkAlphaNoSameKey
405     //         => akeyCheck(.K, .Set) ...</k>
406
407     rule keyCheck(AList(ListItem(AObject(A:K,B:K)) C:List), T:K,
        D:Set, G:List) => keyCheck(AList(C), T, SetItem(A) D,
        ListItem(A) G)
408     rule keyCheck(AList(.List), TList(ListItem(TObject(ModName:K
        , A:K,B:K,C:K)) Rest:List), D:Set, G:List) => keyCheck(
        AList(.List), TList(Rest), SetItem(A) D, ListItem(A) G)
409     rule keyCheck(AList(.List), TList(.List), D:Set, G:List) =>
        lengthCheck(size(G),size(D))
410
411
412     syntax KItem ::= makeAlphaM(K,K) [function] //(Alpha,
        AlphaMap)
413     syntax KItem ::= tAlphaMap(K) //(AlphaMap) temp alphamap
414
415     rule <k> makeAlphaMap
416         => makeAlphaM(A, .Map) ...</k>
417         <tempAlpha> A:K </tempAlpha>
418
419     rule makeAlphaM(AList(ListItem(AObject(A:K,B:K)) C:List), M:
        Map) => makeAlphaM(AList(C), M[A <- B])
420     rule makeAlphaM(AList(.List), M:Map) => tAlphaMap(M)
421
422     rule <k> tAlphaMap(M:K) => .K ...</k>
423         <tempAlphaMap> OldAlphaMap:K => M </tempAlphaMap>
424
425 //     syntax KItem ::= tkeyCheck(K,K,K) [function] //(T,List of
        T,Set of T)
426
427 //     rule <k> checkTNoSameKey
428 //         => tkeyCheck(T, .Set, T) ...</k>
429 //         <tempT> T:K </tempT>
430
```

```
431 //    rule tkeyCheck(TList(ListItem(TObject(A:K,B:K,C:K)) Rest:
      List), D:Set, G:K) => tkeyCheck(TList(Rest), SetItem(A) D, G)
432 //    rule tkeyCheck(TList(.List), D:Set, TList(G:List)) =>
      lengthCheck(size(G),size(D))
433
434    syntax KItem ::= aloopCheck(K,K,K,K,K,K,K) [function] //(
      Alpha,List of Alpha,Set of Alpha,CurrNode,lengthcheck,T,
      BigSet)
435
436    rule <k> checkAlphaNoLoops
437      => aloopCheck(A,.List,.Set,.K,.K,T,.Set) ...</k>
438      <tempAlphaMap> A:K </tempAlphaMap>
439      <tempT> T:K </tempT>
440
441    //aloopCheck set and list to check cycles
442    rule aloopCheck(Alpha:Map (A:KItem |-> B:KItem), D:List, G:
      Set, .K, .K,T:K,S:Set) => aloopCheck(Alpha, ListItem(B)
      ListItem(A) D, SetItem(B) SetItem(A) G, B, .K,T,S)
443    rule aloopCheck(Alpha:Map (H |-> B:KItem), D:List, G:Set, H:
      KItem, .K,T:K,S:Set) => aloopCheck(Alpha, ListItem(B) D,
      SetItem(B) G, B, .K,T,S)
444
445    rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K,T:K,S:
      Set) => aloopCheck(Alpha, .List, .Set, .K, lengthCheck(
      size(G),size(D)),T,G S) //type rename loop ERROR
446      requires (notBool H in keys(Alpha)) andBool (H in
      typeSet(T, .Set) orBool H in S)
447
448    rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K,T:K,S:
      Set) => error //terminal alpha rename is not in T ERROR
449      requires (notBool H in keys(Alpha)) andBool (notBool (H
      in typeSet(T, .Set) orBool H in S))
450
451
452    syntax Set ::= typeSet(K,K) [function] //(K, KSet)
453    rule typeSet(TList(ListItem(TObject(ModName:K, A:K,B:K,C:K))
      Rest:List), D:Set) => typeSet(TList(Rest), SetItem(A) D)
454    rule typeSet(TList(.List), D:Set) => D
455
456 //    rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K) =>
      keys(Alpha) ~> H
457 //      requires notBool H in keys(Alpha)
458
```

```
459     rule aloopCheck(.Map, .List, .Set, .K, .K,T:K, S:Set) => .K
460 //     rule aloopCheck(AList(Front:List ListItem(AObject(H,B:K))
      C:List), D:List, G:Set, H:ConId) => aloopCheck(AList(C:List),
      ListItem(B) D, SetItem(B) G, B)
461
462
463 //     syntax KItem ::= TList(K) //list of T objects for every
      new type introduced by data and newtype
464 //     syntax KItem ::= TObject(K,K,K) //(type name, entire list
      of poly type vars, list of inner T pieces)
465 //     syntax KItem ::= InnerTPiece(K,K,K,K,K) //(type
      constructor, poly type vars, argument sorts, entire constr
      block, type name)
466
467 //Make sure argument sorts [U] [W,V] are in the set of keys of
      alpha and targets of T, (keys of T)
468
469     syntax KItem ::= argSortCheck(K,K,K) [function] //(T,
      AlphaMap)
470
471     rule <k> checkArgSortsAreTargets
472           => argSortCheck(T,A,typeSet(T,.Set)) ...</k>
473     <tempAlphaMap> A:K </tempAlphaMap>
474     <tempT> T:K </tempT>
475
476     rule argSortCheck(TList(ListItem(TObject(ModName:K, A:K,B:K,
      ListItem(InnerTPiece(C:K,D:K,ListItem(Arg:KItem) ArgsRest
      :List,E:K,F:K)) InnerRest:List)) TListRest:List),AlphaMap
      :Map,Tset:Set) => argSortCheck(TList(ListItem(TObject(
      ModName,A,B,ListItem(InnerTPiece(C,D,ArgsRest,E,F))
      InnerRest)) TListRest),AlphaMap,Tset)
477     requires ((Arg in keys(AlphaMap)) orBool (Arg in Tset))
478
479     rule argSortCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,D:K,ListItem(Arg:KItem) ArgsRest
      :List,E:K,F:K)) InnerRest:List)) TListRest:List),AlphaMap
      :Map,Tset:Set) => error
480     requires (notBool ((Arg in keys(AlphaMap)) orBool (Arg
      in Tset)))
481
482     rule argSortCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,D:K,.List,E:K,F:K)) InnerRest:
      List)) TListRest:List),AlphaMap:Map,Tset:Set) =>
```

```

    argSortCheck(TList(ListItem(TObject(ModName,A,B,InnerRest
    )) TListRest),AlphaMap,Tset)
483
484 rule argSortCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,.
    List)) TListRest:List),AlphaMap:Map,Tset:Set) =>
    argSortCheck(TList(TListRest),AlphaMap,Tset)
485
486 rule argSortCheck(TList(.List),AlphaMap:Map,Tset:Set) => .K
487
488 //NEED TO CHECK all the polymorphic parameters from right appear
    on left. RIGHT SIDE ONLY
489 //NEED TO CHECK UNIQUENESS FOR POLY PARAM ON LEFT SIDE ONLY
490
491 syntax KItem ::= parCheck(K,K) [function] //(T,AlphaMap)
492 syntax KItem ::= makeTyVarList(K,K,K) [function] //(TyVars,
    NewList)
493 syntax KItem ::= lengthRet(K,K,K) [function]
494
495 rule <k> checkParUsed
496     => parCheck(T,.K) ...</k>
497     <tempT> T:K </tempT>
498
499 //rule makeParLists(TList(ListItem(TObject(A:K,ListItem(Arg:
    KItem) PolyList:List,C:K)) Rest:List),Tlist:List,Tset:Set
    ) => makeParLists(TList(ListItem(TObject(A,PolyList,C))
    Rest),ListItem(Arg) Tlist,SetItem(Arg) Tset)
500 rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,C:K))
    Rest:List),.K) => parCheck(TList(ListItem(TObject(
    ModName,A:K,B:K,C:K)) Rest:List),makeTyVarList(B,.List,.
    Set))
501
502 rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
    ListItem(InnerTPiece(C:K,ListItem(Par:KItem) ParRest:List
    ,D:K,E:K,F:K)) InnerRest:List)) Rest:List),NewSet:Set) =>
503     parCheck(TList(ListItem(TObject(ModName,A,B,ListItem(
    InnerTPiece(C,ParRest,D,E,F)) InnerRest)) Rest),
    NewSet)
504     requires Par in NewSet
505
506 rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
    ListItem(InnerTPiece(C:K,ListItem(Par:KItem) ParRest:List
    ,D:K,E:K,F:K)) InnerRest:List)) Rest:List),NewSet:Set) =>
    error
```

```
507         requires notBool (Par in NewSet)
508
509     rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
510         ListItem(InnerTPiece(C:K,.List,D:K,E:K,F:K)) InnerRest:
511         List)) Rest:List),NewSet:Set) =>
512         parCheck(TList(ListItem(TObject(ModName,A,B,InnerRest))
513         Rest),NewSet)
514
515     rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,.List
516         )) Rest:List),NewSet:Set) =>
517         parCheck(TList(Rest),NewSet)
518
519     rule parCheck(TList(.List),NewSet:Set) => .K
520
521     rule makeTyVarList('typeVars(A:K,,Rest:K),NewList:List,
522         NewSet:Set) => makeTyVarList(Rest, ListItem(A) NewList,
523         SetItem(A) NewSet)
524
525     rule makeTyVarList(.TyVars,NewList:List,NewSet:Set) =>
526         lengthRet(size(NewList),size(NewSet),NewSet)
527
528     rule lengthRet(A:Int, B:Int, C:K) => C
529         requires A ==Int B
530
531     rule lengthRet(A:Int, B:Int, C:K) => error
532         requires A /=Int B
533
534     //rule argSortCheck(TList(ListItem(TObject(A:K,B:K,C:K)
535
536     //////////////////////////////////////
537
538     // STEP 3 Transform T into beta
539
540     syntax KItem ::= "startTTransform"
541     syntax KItem ::= "constructDelta"
542     syntax KItem ::= "constructBeta"
543
544     rule <k> startTTransform
545         => constructDelta
546         ~> (constructBeta) ...</k>
547
548     rule <k> constructDelta
```

```
542         => makeDelta(T, .Map) ...</k>
543     <tempT> T:K </tempT>
544
545     syntax KItem ::= makeDelta(K, Map) [function] //(T, Delta)
546     syntax KItem ::= newDelta(Map) //Delta
547     syntax KItem ::= newBeta(Map) //beta
548     syntax List ::= retPolyList(K, List) [function] //(T, Delta)
549
550     rule makeDelta(TList(ListItem(TObject(ModName:K, A:K, Polys:K,
551         C:K)) Rest:List), M:Map) =>
552         makeDelta(TList(Rest), M[ModPlusType(ModName, A) <- size(
553             retPolyList(Polys, .List))])
554     rule makeDelta(TList(.List), M:Map) => newDelta(M)
555
556     rule retPolyList('typeVars(A:K, , Rest:K), NewList:List) =>
557         retPolyList(Rest, ListItem(A) NewList)
558     rule retPolyList(.TyVars, L:List) => L
559
560     rule <k> newDelta(M:Map)
561         => .K ...</k>
562     <tempDelta> OldDelta:K => M </tempDelta>
563
564     rule <k> constructBeta
565         => makeBeta(T, .Map) ...</k>
566     <tempT> T:K </tempT>
567
568     syntax KItem ::= makeBeta(K, Map) [function] //(T, Beta, Delta)
569
570     rule makeBeta(TList(ListItem(TObject(ModName:K, A:K, B:K,
571         ListItem(InnerTPiece(Con:K, H:K, D:K, E:K, F:K)) InnerRest:
572         List)) Rest:List), Beta:Map) =>
573         makeBeta(TList(ListItem(TObject(ModName, A, B, InnerRest))
574             Rest), Beta[ModPlusType(ModName, Con) <- betaParser(E
575                 , B, A)])
576     rule makeBeta(TList(ListItem(TObject(ModName:K, A:K, B:K, .List
577         )) Rest:List), Beta:Map) =>
578         makeBeta(TList(Rest), Beta)
579     rule makeBeta(TList(.List), Beta:Map) =>
580         newBeta(Beta)
581 //     rule makeBeta(TList(ListItem(TObject(ModName:K, A:K, B:K,
582     ListItem(InnerTPiece(C:K, H:K, D:K, E:K, F:K)) InnerRest:List))
583     Rest:List), Beta:Map) =>
```

```

574 //      makeBeta(TList(ListItem(TObject(ModName,A,B,InnerRest
      )) Rest),Beta)
575
576 syntax KItem ::= betaParser(K,K,K) [function] //(Tree Piece,
      NewSyntax,Parameters,Constr)
577 syntax Set ::= getTyVarsRHS(K,List) [function]
578
579 syntax KItem ::= forAll(Set,K)
580 syntax KItem ::= funtype(K,K)
581
582 syntax Set ::= listToSet(List, Set) [function]
583
584 rule listToSet(ListItem(A:KItem) L:List, S:Set) => listToSet
      (L, SetItem(A) S)
585 rule listToSet(.List, S:Set) => S
586
587
588 //if optbangAtypes, need to see if first variable is a typecon
589 //if its a typecon then need to go into Delta and see the amount
      of parameters it has
590 //then count the number of optbangAtypes after the typecon
591 rule betaParser('constrCon(A:K,, B:K), Par:K, Con:K) =>
      forAll(getTyVarsRHS(B,.List), betaParser(B, Par, Con))
592 rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeTyVar(Tyv:K)),, Rest:K), Par:K, Con:K) =>
      funtype(Tyv, betaParser(Rest, Par, Con))
593 rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'baTypeCon(A:K,, B:K)),, Rest:K), Par:K, Con:K)
      => funtype('baTypeCon(A:K,, B:K), betaParser(Rest, Par,
      Con))
594 rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeGTyCon(Tyc:K)),, Rest:K), Par:K, Con:K) =>
      funtype(Tyc, betaParser(Rest, Par, Con))
595 rule betaParser(.OptBangATypes, Par:K, Con:K) => '
      simpleTypeCon(Con,, Par)
596 // rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeGTyCon(Tyc:K)),, Rest:KItem)) => getTypeVars(A
      ) getTypeVars(Rest)
597 // rule getTypeVars('optBangAType('emptyBang(.KList),, Rest:K
      )) => getTypeVars(Rest)
598 // rule getTypeVars('atypeGTyCon(A:K)) => .List
599 // rule getTypeVars('atypeTyVar(A:K)) => ListItem(A)
600 // rule getTypeVars(.OptBangATypes) => .List

```

```

601
602     rule getTyVarsRHS(.OptBangATypes, Tylist:List) => listToSet (
        Tylist, .Set)
603
604     rule <k> newBeta (M:Map)
605         => .K ...</k>
606         <tempBeta> OldBeta:K => M </tempBeta>
607
608     //////////////////////////////////////
609
610     //     syntax KItem ::= "insertAlphaBetaStar"
611
612     syntax KItem ::= insertABRec(K, List)
613     syntax KItem ::= insertAB(K)
614
615     rule <k> insertAlphaBetaStar => insertABRec (Mod, Imp) ...</k>
        >
616         <tempModule> Mod:KItem </tempModule>
617         <importTree> Imp:List </importTree>
618
619     rule <k> insertABRec (Node:KItem, ListItem (impObject (B:KItem,
        Node)) I:List) => insertAB (B) ~> insertABRec (Node, I)
        ...</k>
620
621     rule <k> insertABRec (Node:KItem, ListItem (impObject (B:KItem,
        C:KItem)) I:List) => insertABRec (Node, I) ...</k>
622         requires Node =/=K C
623
624     rule <k> insertAB (B) => .K ...</k>
625
626         <tempAlphaStar> Alph:KItem </tempAlphaStar>
627         <tempBetaStar> Bet:KItem </tempBetaStar>
628
629         <moduleName> 'moduleName (B) </moduleName>
630         <moduleImpAlphas> ImpAlphas:List => ListItem (Alph)
            ImpAlphas </moduleImpAlphas>
631         <moduleImpBetas> ImpBetas:List => ListItem (Bet)
            ImpBetas </moduleImpBetas>
632
633
634     endmodule

```

CHAPTER 5

MULTIPLE MODULE SUPPORT

The next step is to implement multiple modules into the Haskell semantics. Similar to including files or objects in other programming languages, Haskell modules can include other modules and use functions, types, and typeclasses declared in the module. There are a several considerations and additional checks that need to be made. Modules need to include other modules There cannot be inclusion cycles Modules need to be able to access user defined types from the other modules that are included When referencing types from other modules, there is a scope where if the user makes another type of the same name in the current module then when the user references the type, it refers to the type from the current module. For instance:

```
1 File 1:
2 module File1 where
3 {data A = B
4 }
5 File 2:
6 module File2 where
7 {data A = B
8 ;data C = B A
9 }
```

This will compile. The A used in data C is File2.A However, If there are multiple types with the same name declared outside of the current module. If you try to refer to the type without the parent module, there will be a compiler error because there is ambiguity. For instance:

```
1 File 1:
2 module File1 where
3 {data A = B
4 }
5 File 2:
6 module File2 where
7 {data A = B
```

```
8 }
9 File 3:
10 module File3 where
11 {import File1
12 ;import File2
13 ;data C = B A
14 }
```

This will not compile because in File 3, type A is ambiguous and can mean File1.A or File2.A Type synonyms need to include polymorphism For instance: The user can write type A a = B a

Since we need to check for module inclusion cycles and also build the set of user defined types for each module and included modules, I decided to use a tree. The plan for the algorithm is as follows 1. Construct tree for module inclusion 2. Check tree for cycles 3. Go to each leaf and recursively go up the tree and build α^* and β^* for the types of the module and the children and desugar the scope so that each type specifies the scope.

Where α is the map of type synonyms declared in the current module and α^* is the map of type synonyms declared in the current module and all the included modules. β is the set of user defined types from using data and newtype declared in the current module. β^* is the set of user defined types from using data and newtype declared in the current module and all the included modules. Desugar the scope means that when the user references a type, desugar the reference to also include the parent module at all times. The syntax also needed to be changed to allow for multiple modules. The new syntax added is

```
1 //  CUSTOM SYNTAX NOT PART OF OFFICAL HASKELL
2
3     syntax ModuleList ::= Module [klabel('modListSingle)] |
      Module "<NEXTMODULE>" ModuleList [klabel('modList)]
```

This is because K cannot read mutiple files. So instead all the included modules for a program are dumped into one file and are seperated by the keyword `¡NEXTMODULE¡` This creates a list of modules called ModuleList.

CHAPTER 6

INFERRNCING

6.1 Data Structures

The next step is the actual type inference algorithm. I needed to create a syntax for polymorphic types that may contain monomorphic type variables and polymorphic type variables. Then I made a map from type constructor names to arities, called Delta. Then I made a map from data constructors and term identifiers to their most general polymorphic types, called beta. The first part was converting the T data structure into beta, which is more suited for type inferencing. Something to note is that mutually recursive functions are allowed in Haskell. For example:

$$fx = yx$$

$$yx = fx$$

This set of functions is allowed to compile. When run, the function just simply runs forever. This is unlike the OCaml semantics, which does not allow for mutually recursive functions.

Another thing to note is that the

1 [context =>]

part of the syntax for the types is deprecated. <https://stackoverflow.com/questions/9345589/guards-vs-if-then-else-vs-cases-in-haskell> For functions, function guards, cases, and if-then-else are all equivalent.

A polymorphic data type looks like $\forall abc, (a \rightarrow b) \rightarrow c$

6.1.1 Inferencing Rules

Haskell is a strong and static type system.

This means that type inferencing can be ran before compilation or running the code. used to ensure that fun

Type inferencing

Haskell's type system is a Hindley-Milner polymorphic type system that has been extended with type classes to account for overloaded function

A type system is a set of rules that assign a property to various constructs in a programming language called type. A type is a property that allows the programmer to add constraints to programs.

6.2 Type theory

Type theory was created by Bertrand Russell to prevent Russell's Paradox for set theory, introduced by Georg Cantor. The issue was that not specifying a certain property for sets allowed sets to contain themselves in Naive Set Theory. So Bertrand Russell prevented this problem by specifying a property called type for objects, and objects cannot contain their own type.

6.3 Lambda Calculus

The Lambda Calculus was created to

6.4 Hindley-Milner

6.5 Definition of Substitution

A substitution is a set of variables and their replacements. Applying a substitution to an expression means to simultaneously replace each variable in the expression with the replacement term.

[<http://www.mathcs.duq.edu/simon/Fall04/notes-7-4/node3.html>]

6.6 Composition of Substitutions

6.7 Inferencing Algorithm

$$\begin{array}{c}
 \frac{}{\Gamma \vdash c : \tau \mid \text{unify}\{(\tau, \text{freshInstance}(\tau))\}} \text{Constant} \\
 \\
 \frac{}{\Gamma \vdash x : \tau \mid \text{unify}\{(\tau, \text{freshInstance}(\Gamma(x)))\}} \text{Variable} \\
 \\
 \frac{[x : \tau_1] + \Gamma \vdash e : \tau_2 \mid \sigma}{\Gamma \vdash \backslash x \rightarrow e : \tau \mid \text{unify}\{(\sigma(\tau), \sigma(\tau_1 \rightarrow \tau_2))\} \circ \sigma} \text{Lambda} \\
 \\
 \frac{\Gamma \vdash e_1 : \text{bool} \mid \sigma_1 \quad \sigma_1(\Gamma) \vdash e_2 : \sigma_1(\tau) \mid \sigma_2 \quad \sigma_2 \circ \sigma_1(\Gamma) \vdash e_3 : \sigma_2 \circ \sigma_1(\tau) \mid \sigma_3}{\Gamma \vdash \text{if } e_1 \text{ then } e_2 \text{ else } e_3 : \tau \mid \sigma_3 \circ \sigma_2 \circ \sigma_1} \text{IfThenElse} \\
 \\
 \frac{\Gamma \vdash e_1 : \tau_1 \rightarrow \tau \mid \sigma_1 \quad \sigma_1(\Gamma) \vdash e_2 : \sigma_1(\tau_1) \mid \sigma_2}{\Gamma \vdash e_1 e_2 : \tau \mid \sigma_2 \circ \sigma_1} \text{Application} \\
 \\
 \frac{}{\Gamma \vdash c : \tau \mid \text{unify}\{(\tau, \text{freshInstance}(\tau))\}} \text{LetIn}
 \end{array}$$

[cs 421 gather exp ty substitution mp]

```

1 requires "haskell-syntax.k"
2 requires "haskell-configuration.k"
3 requires "haskell-preprocessing.k"
4
5 module HASKELL-TYPE-INFERENCING
6     imports HASKELL-SYNTAX
7     imports HASKELL-CONFIGURATION
8     imports HASKELL-PREPROCESSING
9
10    syntax KItem ::= "Bool" //Boolean
11
12    // STEP 4 Type Inferencing
13    syntax KItem ::= inferenceShell(K) [function]//Input,
14                        AlphaMap, Beta, Delta, Gamma
15    //syntax KItem ::= typeInferenceFun(K, Map, Map, Map, Map, K, K) [
16                        function]//Input, Alpha, Beta, Delta, Gamma
17    //syntax KItem ::= typeInferenceFun(Map, K, K) //Gamma,
18                        Expression, Guessed Type
19    syntax Map ::= genGamma(K, Map, K) [function] //Apatlist,
20                        Gamma Type

```

```
17     syntax KItem ::= genLambda(K,K) [function]
18     syntax KItem ::= guessType(Int)
19 //     syntax KItem ::= lambdaReturn(K,K,K)
20     syntax KItem ::= freshInstance(K, Int) [function]
21     syntax Int ::= paramSize(K) [function]
22
23
24     syntax KItem ::= mapBag(Map)
25     syntax KResult ::= mapBagResult(Map)
26
27     syntax Map ::= gammaSub(Map,Map,Map) [function]//
        substitution, gamma
28
29     rule <k> performIndividualInferencing => inferenceShell(Code
        ) ...</k>
30         <tempModule> Mod:KItem </tempModule>
31
32         <moduleName> 'moduleName (Mod) </moduleName>
33         <moduleTempCode> Code:KItem </moduleTempCode>
34
35     rule inferenceShell('topdeclslist('type(A:K,, B:K),, Rest:K)
        ) =>
36         inferenceShell(Rest) //constructalpha
37     rule inferenceShell('topdeclslist('data(A:K,, B:K,, C:K,, D:
        K),, Rest:K)) =>
38         inferenceShell(Rest)
39     rule inferenceShell('topdeclslist('newtype(A:K,, B:K,, C:K,,
        D:K),, Rest:K)) =>
40         inferenceShell(Rest)
41     rule inferenceShell('topdeclslist('class(A:K,, B:K,, C:K,, D
        :K),, Rest:K)) =>
42         inferenceShell(Rest)
43     rule inferenceShell('topdeclslist('instance(A:K,, B:K,, C:K
        ,, D:K),, Rest:K)) =>
44         inferenceShell(Rest)
45     rule inferenceShell('topdeclslist('default(A:K,, B:K,, C:K,,
        D:K),, Rest:K)) =>
46         inferenceShell(Rest)
47     rule inferenceShell('topdeclslist('foreign(A:K,, B:K,, C:K,,
        D:K),, Rest:K)) =>
48         inferenceShell(Rest)
49
50     rule inferenceShell('topdeclslist('topdecldecl(A:K),, Rest:K
```

```

    )) =>
51     typeInferenceFun(.ElemList, .Map, A, guessType(0)) ~>
        inferenceShell(Rest)
52
53
54     rule <k> typeInferenceFun(.ElemList, Gamma:Map, '
        declFunLhsRhs(Fn:K,, Lhsrhs:K), Guess:K) =>
55         typeInferenceFun(.ElemList, Gamma, Lhsrhs, Guess) ...</
            k>
56     rule <k> typeInferenceFun(.ElemList, Gamma:Map, '
        eqExpOptDecls(Ex:K,, Optdecls:K), Guess:K) =>
57         typeInferenceFun(.ElemList, Gamma, Ex, Guess) ...</k>

```

6.7.1 Variable Rule

$$\frac{}{\Gamma \vdash x : \tau \mid \text{unify}\{(\tau, \text{freshInstance}(\Gamma(x)))\}} \text{Variable}$$

```

1     //T-App
2     //rule typeInferenceFun('aexpQVar(Var:K), Alpha:Map, Beta:
        Map, Delta:Map, (Var |-> Sigma:K) Gamma:Map,.K,.K) =>
        Sigma
3     //Gamma Proves x:phi(tau) if Gamma(x) = \forall alpha_1,
        ..., alpha_n . tau
4     //where phi replaces all occurrences of alpha_1, ...,
        alpha_n by monotypes tau_1, ..., tau_n
5
6     rule <k> typeInferenceFun(.ElemList, (Var |-> Type:K) Gamma:
        Map, 'aexpQVar(Var:K), Guess:KItem)
7         => mapBagResult (uniFun (ListItem (uniPair (Guess,
            freshInstance(Type, TypeIt)))) ...</k> //Variable
            rule
8         <typeIterator> TypeIt:Int => TypeIt +Int paramSize(Type
            ) </typeIterator>

```

6.7.2 Constant Rule

$$\frac{}{\Gamma \vdash c : \tau \mid \text{unify}\{(\tau, \text{freshInstance}(\tau))\}} \text{Constant}$$

```

1
2   rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'aexpGCon('
      conTyCon(Mid:K,, Gcon:K)), Guess:KItem)
3       => mapBagResult (uniFun (ListItem (uniPair (Guess,
      freshInstance (Type, TypeIt)))) ...</k> //Constant
      rule
4       <tempBeta> (ModPlusType (Mid,Gcon) |-> Type:K) Beta:Map
      </tempBeta>
5       <typeIterator> TypeIt:Int => TypeIt +Int paramSize (Type
      ) </typeIterator>

```

6.7.3 Lambda Rule

$$\frac{[x : \tau_1] + \Gamma \vdash e : \tau_2 \mid \sigma}{\Gamma \vdash \lambda x \rightarrow e : \tau \mid \text{unify}\{(\sigma(\tau), \sigma(\tau_1 \rightarrow \tau_2))\} \circ \sigma} \text{Lambda}$$

```

1
2   syntax KItem ::= typeInferenceFun (ElemList, Map, K, K) [
      strict(1)]
3   syntax KItem ::= typeInferenceFunLambda (ElemList, K, K, K) [
      strict(1)]
4   /* automatically generated by the strict(1) in typeInferenceFun
      or typeInferenceFunAux
5   rule typeInferenceFunAux (Es:ElemList, C:K, A:K, B:K) => Es ~>
      typeInferenceFun (HOLE, C, A, B)
6       requires notBool isKResult (Es)
7   rule Es:KResult ~> typeInferenceFunAux (HOLE, C:K, A:K, B:K) =>
      typeInferenceFun (Es, C, A, B)
8   */
9
10  //lambda rule
11  rule <k> typeInferenceFun (.ElemList, Gamma:Map, 'lambdaFun (
      Apatlist:K,, Ex:K), Guess:KItem)
12      => typeInferenceFunLambda (val (typeInferenceFun (.
      ElemList, genGamma (Apatlist, Gamma, guessType (TypeIt)
      ), genLambda (Apatlist, Ex), guessType (TypeIt +Int 1)
      )), .ElemList, Guess, guessType (TypeIt), guessType (
      TypeIt +Int 1)) ...</k>
13      <typeIterator> TypeIt:Int => TypeIt +Int 2 </
      typeIterator>
14

```



```

15     rule <k> typeInferenceFunLambda (valValue (mapBagResult (Sigma:
      Map)), .ElemList, Tau:K, Tauone:K, Tautwo:K)
16     => mapBagResult (compose (uniFun (ListItem (uniPair (typeSub
      (Sigma, Tau), typeSub (Sigma, funtype (Tauone, Tautwo))))))
      , Sigma)) ...</k>

```

6.7.4 Application Rule

$$\frac{\Gamma \vdash e_1 : \tau_1 \rightarrow \tau \mid \sigma_1 \quad \sigma_1(\Gamma) \vdash e_2 : \sigma_1(\tau_1) \mid \sigma_2}{\Gamma \vdash e_1 e_2 : \tau \mid \sigma_2 \circ \sigma_1} \text{Application}$$

```

1
2     syntax KItem ::= typeInferenceFunAppli (ElemList, Map, K, K,
      Map) [strict(1)]
3
4     //application rule
5     rule <k> typeInferenceFun (.ElemList, Gamma:Map, 'funApp (Eone
      :K,, Etwo:K), Guess:KItem)
6     => typeInferenceFunAppli (val (typeInferenceFun (.
      ElemList, Gamma, Eone, funtype (guessType (TypeIt),
      Guess))), .ElemList, Gamma, Etwo, guessType (TypeIt)
      , .Map) ...</k>
7     <typeIterator> TypeIt:Int => TypeIt +Int 1 </
      typeIterator>
8
9     rule <k> typeInferenceFunAppli (valValue (mapBagResult (
      Sigmaone:Map)), .ElemList, Gamma:Map, Etwo:KItem,
      guessType (TypeIt:Int), .Map)
10    => typeInferenceFunAppli (val (typeInferenceFun (.
      ElemList, gammaSub (Sigmaone, Gamma, .Map), Etwo,
      typeSub (Sigmaone, guessType (TypeIt)))), .ElemList,
      .Map, .K, .K, Sigmaone) ...</k>
11
12    rule <k> typeInferenceFunAppli (valValue (mapBagResult (
      Sigmatwo:Map)), .ElemList, .Map, .K, .K, Sigmaone:Map)
13    => mapBagResult (compose (Sigmatwo, Sigmaone)) ...</k>

```

6.7.5 IfThenElse Rule

$$\frac{\Gamma \vdash e_1 : \text{bool} \mid \sigma_1 \quad \sigma_1(\Gamma) \vdash e_2 : \sigma_1(\tau) \mid \sigma_2 \quad \sigma_2 \circ \sigma_1(\Gamma) \vdash e_3 : \sigma_2 \circ \sigma_1(\tau) \mid \sigma_3}{\Gamma \vdash \text{if } e_1 \text{ then } e_2 \text{ else } e_3 : \tau \mid \sigma_3 \circ \sigma_2 \circ \sigma_1} \text{IfThenElse}$$

```

1      syntax KItem ::= typeInferenceFunIfThen(ElemList, Map, K, K,
2          K, Map, Map) [strict(1)]
3
4      //if_then_else rule
5      rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'ifThenElse(
6          Eone:K,, Optsem:K,, Etwo:K,, Optsemtwo:K,, Ethree:K),
7          Guess:KItem)
8          => typeInferenceFunIfThen(val(typeInferenceFun(.
9              ElemList, Gamma, Eone, Bool)), .ElemList, Gamma,
10              Etwo, Ethree, Guess, .Map, .Map) ...</k>
11
12     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
13         Sigmaone:Map)), .ElemList, Gamma:Map, Etwo:KItem, Ethree:
14         KItem, Guess:KItem, .Map, .Map)
15         => typeInferenceFunIfThen(val(typeInferenceFun(.
16             ElemList, gammaSub(Sigmaone, Gamma, .Map), Etwo,
17             typeSub(Sigmaone, Guess)), .ElemList, Gamma, .K,
18             Ethree, Guess, Sigmaone, .Map) ...</k>
19
20     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
21         Sigmatwo:Map)), .ElemList, Gamma:Map, .K, Ethree:KItem,
22         Guess:KItem, Sigmaone:Map, .Map)
23         => typeInferenceFunIfThen(val(typeInferenceFun(.
24             ElemList, gammaSub(compose(Sigmatwo, Sigmaone),
25             Gamma, .Map), Ethree, typeSub(compose(Sigmatwo,
26             Sigmaone), Guess)), .ElemList, .Map, .K, .K, .K,
27             Sigmaone, Sigmatwo) ...</k>
28
29     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
30         Sigmathree:Map)), .ElemList, .Map, .K, .K, .K, Sigmaone:
31         Map, Sigmatwo:Map)
32         => mapBagResult(compose(compose(Sigmathree, Sigmatwo),
33             Sigmaone)) ...</k>

```

6.7.6 LetIn Rule

The LetIn Rule must allow for mutual recursion. This means that an example program that must be inferred is

```
1 let {f = \x -> y x; y = \x -> f x} in (f 2)
```

In this example, the f is an expression that refers to y and y is an expression that refers to f .

$$\frac{}{\Gamma \vdash c : \tau \mid \text{unify}\{\tau, \text{freshInstance}(\tau)\}} \text{LetIn}$$

```
1
2  syntax KItem ::= typeInferenceFunLetIn(ElemList, Map, Map, K
      , K, K, Int, Int, Map, Map) [strict(1)]
3  syntax KItem ::= grabLetDeclName(K, Int) [function]
4  syntax KItem ::= grabLetDeclExp(K, Int) [function]
5  syntax KItem ::= mapLookup(Map, K) [function]
6  syntax Map ::= makeDeclMap(K, Int, Map) [function]
7  syntax Map ::= applyGEN(Map, Map, Map, Map) [function]
8
9  //Haskell let in rule (let rec in exp + let in rule combined
      )
10 //gamma |- let rec f1 = e1 and f2 = e2 and f3 = e3 .... in e
      =>
11 //beta, [f1 -> tau1, f2 -> tau2, f3 -> tau3,...] + gamma |-
      e1 : tau1 | sigma1, [f1 -> sigma1(tau1), f2 -> sigma1(
      tau2), f3 -> sigma1(tau3),....] + sigma1(gamma) |- e2 :
      sigma1(tau2) | sigma2 [f1 -> sigma2 o sigma1(tau1), f2
      -> sigma2 o sigma1(tau2), f3 -> sigma2 o sigma1(tau3)
      ,....] + sigma2 o sigma1(gamma) |- e3 : sigma2 o sigma1(
      tau3) ..... [f1 -> gen(sigma_n o sigma2 o sigma1(tau1),
      sigma_n o sigma2 o sigma1(Gamma)), f2 -> gen(tau2), f3 ->
      gen(tau3),....] + gamma |- e : something
12 rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'letIn(D:K,,
      E:K), Guess:KItem)
13   => typeInferenceFunLetIn(.ElemList, Gamma, makeDeclMap
      (D, TypeIt, .Map), D, E, Guess, 0, TypeIt, .Map,
      Beta) ...</k>
14   <typeIterator> TypeIt:Int => TypeIt +Int size(
      makeDeclMap(D, TypeIt, .Map)) </typeIterator>
15   <tempBeta> Beta:Map </tempBeta>
16
```

```
17     rule <k> typeInferenceFunLetIn(.ElemList, Gamma:Map, DeclMap
      :Map, D:KItem, E:KItem, Guess:KItem, Iter:Int, TypeIt:Int
      , OldSigma:Map, Beta:Map)
18         => typeInferenceFunLetIn(val(typeInferenceFun(.
      ElemList, Gamma DeclMap, grabLetDeclExp(D, Iter),
      mapLookup(DeclMap, grabLetDeclName(D, Iter))), .
      ElemList, Gamma, DeclMap, D, E, Guess, Iter,
      TypeIt, OldSigma, Beta) ...</k>
19     //=> typeInferenceFunLetIn(val(typeInferenceFun(
      DeclMap, grabLetDeclExp(D, Iter +Int TypeIt), Guess
      )), .ElemList, Gamma, DeclMap, D, E, Guess, Iter,
      TypeIt, OldSigma) ...</k>
20     requires Iter <Int (size(DeclMap))
21
22     rule <k> typeInferenceFunLetIn(valValue(mapBagResult(Sigma:
      Map)), .ElemList, Gamma:Map, DeclMap:Map, D:KItem, E:
      KItem, Guess:KItem, Iter:Int, TypeIt:Int, OldSigma:Map,
      Beta:Map)
23         => typeInferenceFunLetIn(.ElemList, gammaSub(Sigma,
      Gamma,.Map), gammaSub(Sigma, DeclMap,.Map), D, E,
      typeSub(Sigma, Guess), Iter +Int 1, TypeIt, compose
      (Sigma,OldSigma), Beta) ...</k>
24     requires Iter <Int (size(DeclMap))
25
26     rule <k> typeInferenceFunLetIn(.ElemList, Gamma:Map, DeclMap
      :Map, D:KItem, E:KItem, Guess:KItem, Iter:Int, TypeIt:Int
      , OldSigma:Map, Beta:Map)
27         => typeInferenceFunLetIn(val(typeInferenceFun(.
      ElemList, Gamma applyGEN(Gamma, DeclMap, .Map, Beta
      ), E, Guess)), .ElemList, Gamma, DeclMap, D, E,
      Guess, Iter, TypeIt, OldSigma, Beta) ...</k>
28     requires Iter >=Int (size(DeclMap))
29
30     rule <k> typeInferenceFunLetIn(valValue(mapBagResult(Sigma:
      Map)), .ElemList, Gamma:Map, DeclMap:Map, D:KItem, E:
      KItem, Guess:KItem, Iter:Int, TypeIt:Int, OldSigma:Map,
      Beta:Map)
31         => mapBagResult(compose(Sigma, OldSigma))...</k>
32     requires Iter >=Int (size(DeclMap))


---


1
2     rule mapLookup((Name |-> Type:KItem) DeclMap:Map, Name:KItem
      ) => Type
```

```
3     rule mapLookup(DeclMap:Map, Name:KItem) => Name
4         requires notBool(Name in keys(DeclMap))
5
6     rule makeDeclMap('decls(Dec:K), TypeIt:Int, NewMap:Map) =>
7         makeDeclMap(Dec, TypeIt, NewMap)
8
9     rule makeDeclMap('declsList('declPatRhs('apatVar(Var:K),,
10         Righthand:K),, Rest:K), TypeIt:Int, NewMap:Map) =>
11         makeDeclMap('decls(Rest), TypeIt +Int 1, NewMap[Var <-
12             guessType(TypeIt)])
13
14     rule makeDeclMap(.DeclList, TypeIt:Int, NewMap:Map) =>
15         NewMap
16
17     rule grabLetDeclName('decls(Dec:K), Iter:Int) =>
18         grabLetDeclName(Dec, Iter)
19
20     rule grabLetDeclName('declsList(Dec:K,, Rest:K), Iter:Int)
21         => grabLetDeclName(Rest, Iter -Int 1)
22         requires Iter >Int 0
23
24     rule grabLetDeclName('declsList('declPatRhs('apatVar(Var:K)
25         ,, Righthand:K),, Rest:K), Iter:Int) => Var
26         requires Iter <=Int 0
27
28     rule grabLetDeclExp('decls(Dec:K), Iter:Int) =>
29         grabLetDeclExp(Dec, Iter)
30
31     rule grabLetDeclExp('declsList(Dec:K,, Rest:K), Iter:Int) =>
32         grabLetDeclExp(Rest, Iter -Int 1)
33         requires Iter >Int 0
34
35     rule grabLetDeclExp('declsList('declPatRhs('apatVar(Var:K),,
36         Righthand:K),, Rest:K), Iter:Int) => grabLetDeclExp(
37         Righthand, Iter)
38         requires Iter <=Int 0
39
40     rule grabLetDeclExp('eqExpOptDecls(Righthand:K,, Opt:K),
41         Iter:Int) => 'eqExpOptDecls(Righthand,, Opt)
42
43     rule genGamma('apatVar(Vari:K), Gamma:Map, Guess:K) => Gamma
44         [Vari <- Guess]
45
46     rule genGamma('apatCon(Vari:K,, Pattwo:K), Gamma:Map, Guess:
47         K) => Gamma[Vari <- Guess]
48
49     rule genLambda('apatVar(Vari:K), Ex:K) => Ex
50
51     rule genLambda('apatCon(Vari:K,, Pattwo:K), Ex:K) => '
52         lambdaFun(Pattwo,, Ex)
```

```
30
31   rule gammaSub(Sigma:Map, (Key:KItem |-> Type:KItem) Gamma:
      Map, Newgamma:Map)
32     => gammaSub(Sigma, Gamma, Newgamma[Key <- typeSub(Sigma,
      Type) ] )
33
34   rule gammaSub(Sigma:Map, .Map, Newgamma:Map)
35     => Newgamma
36
37   rule freshInstance(guessType(TypeIt:Int), Iter:Int) =>
      guessType(TypeIt)
38   rule freshInstance(forAll(.Set, B:K), Iter:Int) => B
39   rule freshInstance(forAll(SetItem(C:KItem) A:Set, B:K), Iter
      :Int) => freshInstance(forAll(A, freshInstanceInner(C, B,
      Iter)), Iter +Int 1)
40
41   syntax KItem ::= freshInstanceInner(K,K,Int) [function]
42
43   rule freshInstanceInner(Repl:KItem, funtype(A:K, B:K), Iter:
      Int) => funtype(freshInstanceInner(Repl,A,Iter),
      freshInstanceInner(Repl,B,Iter))
44   rule freshInstanceInner(Repl:KItem, Repl, Iter:Int) =>
      guessType(Iter)
45   rule freshInstanceInner(Repl:KItem, Target:KItem, Iter:Int)
      => Target [owise]
46
47   rule paramSize(forAll(A:Set, B:K)) => size(A)
48   rule paramSize(A:K) => 0 [owise]
49
50
51   rule applyGEN(Gamma:Map, (Key:KItem |-> Type:KItem) DeclMap
      :Map, NewMap:Map, Beta:Map)
52     => applyGEN(Gamma, DeclMap, NewMap[Key <- gen(Gamma, Type
      , Beta)], Beta)
53
54   rule applyGEN(Gamma:Map, .Map, NewMap:Map, Beta:Map)
55     => NewMap
56
57   //GEN
58   //GEN(Gamma, Tau) => Forall alpha
59
60   syntax KItem ::= gen(Map, K, Map) [function]
61   syntax Set ::= freeVarsTy(K, Map) [function]
```

```

62     syntax Set ::= freeVarsEnv(Map, Map) [function]
63
64
65     rule gen(Gamma:Map, forAll(Para:Set, Tau:KItem), Beta:Map)
        => forAll(freeVarsTy(forAll(Para:Set, Tau), Beta) -Set
            freeVarsEnv(Gamma, Beta), Tau)
66     rule gen(Gamma:Map, Tau:KItem, Beta:Map) => forAll(
        freeVarsTy(Tau, Beta) -Set freeVarsEnv(Gamma, Beta), Tau)
        [owise]
67
68     //rule gen(Gamma:Map, forAll(Para:Set, Tau:KItem), Beta:Map)
        => forAll(freeVarsTy(forAll(Para:Set, Tau), Beta) -Set
            freeVarsEnv(Gamma, Beta), Tau)
69
70     rule freeVarsTy(guessType(TypeIt:Int), Beta:Map) => SetItem(
        guessType(TypeIt:Int))
71     rule freeVarsTy(funtype(Tauone:KItem, Tautwo:KItem), Beta:
        Map) => freeVarsTy(Tauone, Beta) freeVarsTy(Tautwo, Beta)
72     rule freeVarsTy(Tau:KItem, Beta:Map) => .Set
73         requires (forAll(.Set, Tau)) in values(Beta)
74     rule freeVarsTy(forAll(Para:Set, Tau:KItem), Beta:Map) =>
        freeVarsTy(Tau, Beta) -Set Para
75     rule freeVarsEnv(Gamma:Map, Beta:Map) => listToSet(values(
        Beta), .Set)

```

6.8 Unification Algorithm

Let $S = \{(s_1, t_1), (s_2, t_2), \dots, (s_n, t_n)\}$ be a unification problem.

Case $S = \{\}$: $\text{Unif}(S) = \text{Identity function}$ (ie no substitution)

Case $S = (s, t) \cup S'$: Four main steps

Delete: if $s = t$ (they are the same term) then $\text{Unif}(S) = \text{Unif}(S')$

Decompose: if $s = f(q_1, \dots, q_m)$ and $t = f(r_1, \dots, r_m)$ (same f, same m!), then $\text{Unif}(S) = \text{Unif}(\{(q_1, r_1), \dots, (q_m, r_m)\} \cup S')$

Orient: if $t = x$ is a variable, and s is not a variable, $\text{Unif}(S) = \text{Unif}(\{(x, s)\} \cup S')$

Eliminate: if $s = x$ is a variable, and x does not occur in t (the occurs check), then

Let $\phi = x \mapsto t$

Let $\psi = \text{Unif}(\phi(S'))$

$\text{Unif}(S) = \{x \mapsto \psi(t)\} \circ \psi$

Note: $x \multimap a$ o $y \multimap b = y \multimap (x \multimap a(b))$ o $x \multimap a$ if y not in a

[cs 421 class notes]

```
1      //Unification
2
3      syntax Map ::= uniFun(List) [function]
4      syntax Bool ::= isVarType(K) [function]
5      syntax Bool ::= notChildVar(K,K) [function]
6      syntax KItem ::= uniPair(K,K)
7
8      syntax List ::= uniSub(Map,K) [function] //apply
          substitution to unification
9
10     syntax KItem ::= typeSub(Map,K) [function] //apply
          substitution to type
11     syntax Map ::= compose(Map,Map) [function]
12
13     rule uniFun(.List) => .Map //substi(.K,.K) is id
          substitution
14
15     rule uniFun(ListItem(uniPair(S:K,S)) Rest:List) => uniFun(
          Rest) //delete rule
16
17     rule uniFun(ListItem(uniPair(S:K,T:K)) Rest:List) => uniFun(
          ListItem(uniPair(T,S)) Rest) //orient rule
18         requires isVarType(T) andBool (notBool isVarType(S))
19
20     rule uniFun(ListItem(uniPair(funtype(A:K, B:K), funtype(C:K,
          D:K))) Rest:List) => uniFun(ListItem(uniPair(A, C))
          ListItem(uniPair(B, D)) Rest:List) //decompose rule
          function type
21
22     rule uniFun(ListItem(uniPair(S:K,T:K)) Rest:List)
23         => compose((S |-> typeSub(uniFun(uniSub((S |-> T),Rest)),T
          )),uniFun(uniSub((S |-> T),Rest))) //eliminate rule
24     // => compose(uniFun(uniSub((S |-> T),Rest)),(S |-> typeSub
          (uniFun(uniSub((S |-> T),Rest)),T))) //eliminate rule
25         requires isVarType(S) andBool notChildVar(S,T)
26
27     rule isVarType(S:K) => true
28         requires getKLabel(S) ==KLabel 'guessType
```



```
29     rule isVarType(S:K) => false [owise]
30
31     rule notChildVar(S:K,T:K) => true
32
33     rule uniSub(Sigma:Map, .List) => .List
34     rule uniSub(.Map, L:List) => L
35     rule uniSub(Sigma:Map, Rest:List ListItem(uniPair(A:K, B:K))
36         ) => uniSub(Sigma, Rest) ListItem(uniPair(typeSub(Sigma,
37             A), typeSub(Sigma, B)))
38
39     //rule typeSub(substi(.Map), Tau:KItem) => Tau
40     rule typeSub(Sigma:Map (Tau |-> Newtau:KItem), Tau:KItem) =>
41         typeSub(Sigma (Tau |-> Newtau), Newtau)
42     rule typeSub(Sigma:Map, funtype(Tauone:KItem, Tautwo:KItem))
43         => funtype(typeSub(Sigma, Tauone), typeSub(Sigma, Tautwo))
44     rule typeSub(Sigma:Map, Tau:KItem) => Tau [owise]
45
46     syntax Map ::= composeIn(Map, Map, Map, K, K) [function]
47
48     rule compose(Sigmaone:Map, Sigmatwo:Map) => composeIn(
49         Sigmaone, Sigmatwo, .Map, .K, .K)
50
51     rule composeIn(Sigmaone:Map, (Key:KItem |-> Type:KItem)
52         Sigmatwo:Map, NewMap:Map, .K, .K) => composeIn(Sigmaone,
53         Sigmatwo, NewMap, Key, Type)
54
55     rule composeIn((Keyone |-> Typetwo:KItem) Sigmaone:Map,
56         Sigmatwo:Map, NewMap:Map, Keyone:KItem, Typeone:KItem) =>
57         composeIn(Sigmaone, Sigmatwo, NewMap, Keyone, Typeone)
58
59     rule composeIn((Typeone |-> Typetwo:KItem) Sigmaone:Map,
60         Sigmatwo:Map, NewMap:Map, Keyone:KItem, Typeone:KItem) =>
61         composeIn((Typeone |-> Typetwo) Sigmaone, Sigmatwo,
62         NewMap[Keyone <- Typetwo], .K, .K)
63         requires notBool(Keyone in keys(Sigmaone))
64
65     rule composeIn(Sigmaone:Map, Sigmatwo:Map, NewMap:Map,
66         Keyone:KItem, Typeone:KItem) => composeIn(Sigmaone,
67         Sigmatwo, NewMap[Keyone <- Typeone], .K, .K) [owise]
68
69     rule composeIn(Sigmaone:Map, .Map, NewMap:Map, .K, .K) =>
70         Sigmaone NewMap
71 endmodule
```

CHAPTER 7

CONCLUSION

This project helped me with my K knowledge. I also learned a lot about how compilers work and how programming languages are defined. Also, defining yet another real word language in K allows the K-framework to become more popular as another community can learn about it and utilize it. The more that real world languages are defined in K, the more potential K has to become a popular language in industry.

APPENDIX A

HASKELL-SYNTAX.K

```
1 // Syntax from haskell 2010 Report
2 // https://www.haskell.org/onlinereport/haskell2010/haskellch10.
   html#x17-17500010
3
4 module HASKELL-SYNTAX
5
6     syntax Integer ::= Token{ ([0-9]+)
7         | (([0][o]|[0][O])[0-7]+)
8         | (([0][x] | [0][X])[0-9a-fA-F]+) } [onlyLabel]
9
10    syntax CusFloat ::= Token{ ([0-9]+[\.][0-9]+([e E
11        ][\+|-]?[0-9]+)?)
12        | ([0-9]+[e E][\+|-]?[0-9]+) } [
13            onlyLabel]
14
15    syntax CusChar ::= Token{ [\'] (~[\'\\&]) [\'] } [onlyLabel]
16    syntax CusString ::= Token{ [\" ] (~[\"\\&]*) [\" ] } [onlyLabel]
17    syntax VarId ::= Token{ [a-z\_][a-z A-Z\_0-9\']* } [onlyLabel]
18        | "size" [onlyLabel]
19    syntax ConId ::= Token{ [A-Z][a-zA-Z\_0-9\']* } [onlyLabel]
20    syntax VarSym ::= Token{
21        ([\! \# \$ \% \& \* \+ \/ \> \? \^][\! \# \$ \% \& \* \+ \.
22            \/ \< \= \> \? \@ \\\ \^ \\\ \- \~ \:]* )
23        | [\ - ] | [\ . ]
24        | ([\ .][\! \# \$ \% \& \* \+ \/ \< \= \> \? \@ \\\ \^ \\\ \- \~
25            \:][\! \# \$ \% \& \* \+ \. \/ \< \= \> \? \@ \\\ \^ \\\ \-
26            \~ \:]* )
27        | ([\ -][\! \# \$ \% \& \* \+ \. \/ \< \= \> \? \@ \\\ \^ \\\ \-
28            \~ \:][\! \# \$ \% \& \* \+ \. \/ \< \= \> \? \@ \\\ \^ \\\ \-
29            \~ \:]* )
30        | ([\@][\! \# \$ \% \& \* \+ \. \/ \< \= \> \? \@ \\\ \^ \\\ \-
31            \~ \:]* )
32        | ([\~][\! \# \$ \% \& \* \+ \. \/ \< \= \> \? \@ \\\ \^ \\\ \-
33            \~ \:]* )
34    }
```

```

23 | ([\\][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~ \\:]+)
24 | ([\\|][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~ \\:]+)
25 | ([\\:][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~ \\:]*)
26 | ([\\<][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\~
    \\:][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~ \\:]*)
27 | ([\\=][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\? \\@ \\ \\ ^ \\| \\~
    \\:][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\< \\= \\> \\? \\@ \\ \\ ^ \\| \\-
    \\~ \\:]*)*} [onlyLabel]
28 syntax ConSym ::= Token{[\\:][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\<
    \\= \\> \\? \\@ \\ \\ ^ \\| \\- \\~][\\! \\# \\$ \% \\& \\* \\+ \\. \\/ \\<
    \\= \\> \\? \\@ \\ \\ ^ \\| \\- \\~ \\:]*} [onlyLabel]
29
30 syntax IntFloat ::= "(" Integer ")" [bracket] //NOT
    OFFICIAL SYNTAX
31 | "(" CusFloat ")" [bracket]
32 syntax Literal ::= IntFloat | CusChar | CusString
33 syntax TyCon ::= ConId
34 syntax ModId ::= ConId | ConId "." ModId [klabel('conModId)
    ]
35 syntax QTyCon ::= TyCon | ModId "." TyCon [klabel('conTyCon)
    ]
36 syntax QVarId ::= VarId | ModId "." VarId [klabel('qVarIdCon
    )]
37 syntax QVarSym ::= VarSym | ModId "." VarSym [klabel('
    qVarSymCon)]
38 syntax QConSym ::= ConSym | ModId "." ConSym [klabel('
    qConSymCon)]
39 syntax TyVars ::= List{TyVar, ""} [klabel('typeVars)] //used
    in SimpleType syntax
40 syntax TyVar ::= VarId
41 syntax TyVarTuple ::= TyVar "," TyVar [klabel('
    twoTypeVarTuple)]
42 | TyVar "," TyVarTuple [klabel('
    typeVarTupleCon)]
43
44 syntax Con ::= ConId | "(" ConSym ")" [klabel('
    conSymBracket)]

```

```
45     syntax Var ::= VarId | "(" VarSym ")" [klabel('
        varSymBracket)]
46     syntax QVar ::= QVarId | "(" QConSym ")" [klabel('
        qVarBracket)]
47     syntax QCon ::= QTyCon | "(" GConSym ")" [klabel('
        gConBracket)]
48
49     syntax QConOp ::= GConSym | "\"" QTyCon "\"" [klabel('
        qTyConQuote)]
50     syntax QVarOp ::= QVarSym | "\"" QVarId "\"" [klabel('
        qVarIdQuote)]
51     syntax VarOp ::= VarSym | "\"" VarId "\"" [klabel('
        varIdQuote)]
52     syntax ConOp ::= ConSym | "\"" ConId "\"" [klabel('
        conIdQuote)]
53
54     syntax GConSym ::= ":" | QConSym
55     syntax Vars ::= Var
56                   | Var "," Vars [klabel('varCon)]
57     syntax VarsType ::= Vars "::" Type [klabel('varAssign)]
58     syntax Ops ::= Op
59                   | Op "," Ops [klabel('opCon)]
60     syntax Fixity ::= "infixl" | "infixr" | "infix"
61     syntax Op ::= VarOp | ConOp
62     syntax CQName ::= Var | Con | QVar
63
64     syntax QOp ::= QVarOp | QConOp
65
66     syntax ModuleName ::= "module" ModId [klabel('moduleName)]
67
68     syntax Module ::= ModuleName "where" Body [klabel('
        module)]
69                   | ModuleName Exports "where" Body [klabel('
        moduleExp)]
70                   | Body [klabel('
        moduleBody)]
71
72     syntax Body ::= "{" ImpDecls ";" TopDecls "}" [klabel('
        bodyimpandtop)]
73                   | "{" ImpDecls "}" [klabel('bodyimpdecls)]
74                   | "{" TopDecls "}" [klabel('bodytopdecls)]
75
76     syntax ImpDecls ::= List{ImpDecl, ";"} [klabel('impDecls)]
```

```
77     syntax Exports ::= "(" ExportList OptComma ")"
78     syntax ExportList ::= List{Export, ","}
79
80     syntax Export ::= QVar
81                     | QTyCon OptCQList
82                     | ModuleName
83
84     //optional cname list
85     syntax OptCQList ::= "(.)"
86                       | "(" CQList ")" [klabel('cqListBracket
87                                     //Liyi: a check needs to place in
88                                     preprocessing to check
89                                     //if the CQList is a cname list or a
90                                     qvar list.
91                                     | "" [onlyLabel, klabel('
92                                     emptyOptCNameList)]
93     syntax CQList ::= List{CQName, ","}
94
95     syntax ImpDecl ::= "import" OptQualified ModId OptAsModId
96                     OptImpSpec [klabel('impDecl)]
97                     | "" [onlyLabel, klabel('emptyImpDecl)]
98     syntax OptQualified ::= "qualified"
99                           | "" [onlyLabel, klabel('
100                          emptyQualified)]
101
102     syntax OptAsModId ::= "as" ModId
103                       | "" [onlyLabel, klabel('
104                       emptyOptAsModId)]
105
106     syntax OptImpSpec ::= ImpSpec
107                       | "" [onlyLabel, klabel('
108                       emptyOptImpSpec)]
109
110     syntax ImpSpecKey ::= "(" ImportList OptComma ")"
111     syntax ImpSpec ::= ImpSpecKey
112                     | "hiding" ImpSpecKey
113
114     syntax ImportList ::= List{Import, ","}
115
116     syntax Import ::= Var
117                   | TyCon CQList
118
119     syntax TopDecls ::= List{TopDecl, ";"} [klabel('topdeclslist
120                                     )]
```

```
111
112   syntax TopDecl ::= Decl [klabel('topdecldecl)]
113                       > "type" SimpleType "=" Type [klabel('type)
114                       ]
115                       | "data" OptContext SimpleType OptConstrs
116                       | "newtype" OptContext SimpleType "="
117                       | "class" OptContext ConId TyVar OptCDecls
118                       | "instance" OptContext QTyCon Inst
119                       | "default" Types [klabel('default)]
120                       | "foreign" FDecl [klabel('foreign)]
121
122   syntax FDecl ::= "import" CallConv CusString Var "::" FType
123                       | "import" CallConv Safety CusString Var "::"
124                       | "export" CallConv Safety CusString Var "::"
125                       FType
126                       //Liyi: fdecl needs to use special function in preprocessing
127                       // to get the actually elements from the impent and expent
128                       // from the CusString
129                       //did string analysis
130
131   syntax Safety ::= "unsafe" | "safe"
132
133   syntax CallConv ::= "ccall" | "stdcall" | "cplusplus" | "jvm
134                       " | "dotnet"
135
136   syntax FType ::= FrType
137                       | FaType "->" FType // unsure about this one
138                       syntax is ambiguous UNFINISHED
139
140   syntax FrType ::= FaType
141                       | "()"
142
143   syntax FaType ::= QTyCon ATypeList
144
145   //define declaration.
146   syntax OptDecls ::= "where" Decls | "" [onlyLabel, klabel('
147                       emptyOptDecls)]
148
149   syntax Decls ::= "{" DeclsList "}" [klabel('decls)]
150
151   syntax DeclsList ::= List{Decl, ";"} [klabel('declsList)]
```

```
143
144     syntax Decl ::= GenDecl
145                   | FunLhs Rhs [klabel('declFunLhsRhs)]
146                   | Pat Rhs [klabel('declPatRhs)]
147
148     syntax OptCDecls ::= "where" CDecls | "" [onlyLabel, klabel
149                   ('emptyOptCDecls)]
150     syntax CDecls ::= "{" CDeclsList "}"
151     syntax CDeclsList ::= List{CDecl, ";"}
152
153     syntax CDecl ::= GenDecl
154                   | FunLhs Rhs
155                   | Var Rhs
156
157     syntax OptIDecls ::= "where" IDecls | "" [onlyLabel, klabel
158                   ('emptyOptIDecls)]
159     syntax IDecls ::= "{" IDeclsList "}"
160     syntax IDeclsList ::= List{IDecl, ";"} [klabel('ideclslist)]
161
162     syntax IDecl ::= FunLhs Rhs [klabel('cdeclFunLhsRhs)]
163                   | Var Rhs [klabel('cdeclVarRhs)]
164                   | "" [onlyLabel, klabel('emptyIDecl)]
165
166     syntax GenDecl ::= VarsType
167                   | Vars "::" Context "=>" Type [klabel('
168                   genAssignContext)]
169                   | Fixity Ops
170                   | Fixity Integer Ops
171                   | "" [onlyLabel, klabel('emptyGenDecl)]
172
173     //three optional data type for the TopDecl data operator.
174     //deriving data type
175     syntax OptDeriving ::= Deriving | "" [onlyLabel, klabel('
176                   emptyDeriving)]
177     syntax Deriving ::= "deriving" DClass
178                   | "deriving" "(" DClassList ")"
179     syntax DClassList ::= List{DClass, ","}
180     syntax DClass ::= QTyCon
181
182     syntax FunLhs ::= Var APatList [klabel('varApatList)]
183                   | Pat VarOp Pat [klabel('patVarOpPat)]
184                   | "(" FunLhs ")" APatList [klabel('
185                   funlhsApatList)]
```



```

181
182     syntax Rhs ::= "=" Exp OptDecls [klabel('eqExpOptDecls)]
183               | GdRhs OptDecls [klabel('gdRhsOptDecls)]
184
185     syntax GdRhs ::= Guards "=" Exp
186                   | Guards "=" Exp GdRhs
187
188     syntax Guards ::= "|" GuardList
189     syntax GuardList ::= Guard | Guard "," GuardList [klabel('
        guardListCon)]
189
190     syntax Guard ::= Pat "<-" InfixExp
191                   | "let" Decls
192                   | InfixExp
193
194     //definition of exp
195     syntax Exp ::= InfixExp
196                 > InfixExp "::" Type [klabel('expAssign)]
197                 | InfixExp "::" Context "=>" Type [klabel('
        expAssignContext)]
198
199     syntax InfixExp ::= LExp
200                     > "-" InfixExp [klabel('minusInfix)]
201                     > LExp QOp InfixExp
202
203     syntax LExp ::= AExp
204                 > "\" APatList "->" Exp [klabel('lambdaFun)]
205                 | "let" Decls "in" Exp [klabel('letIn)]
206                 | "if" Exp OptSemicolon "then" Exp
207                   OptSemicolon "else" Exp [klabel('ifThenElse
        )]
208                 | "case" Exp "of" "{" Alts "}" [klabel('caseOf
        )]
209                 | "do" "{" Stmts "}" [klabel('doBlock)]

```

LExp is an important sort for the inference function. This is because LExp defines the different expression types which the inference function has specific rules for.

```

1
2     syntax OptSemicolon ::= ";" | "" [onlyLabel, klabel('
        emptySemicolon)]
3
4     syntax OptComma ::= "," | "" [onlyLabel, klabel('
        emptyComma)]

```

```

5      syntax AExp ::= QVar [klabel('aexpQVar)]
6                      | GCon [klabel('aexpGCon)]
7                      | Literal [klabel('aexpLiteral)]
8                      > AExp AExp [left, klabel('funApp)]
9                      > QCon "{" FBindList "]"
10                     | AExp "{" FBindList "]" //aexp cannot be qcon
                        UNFINISHED
11                     //Liyi: first, does not understand the
                        syntax, it is the Qcon {FBindlist}
12                     //or QCon? Second, place a check in
                        preprosssing.
13                     //and also check the Fbindlist here
                        must be at least one argument
14                     > "(" Exp ")" [bracket]
15                     | "(" ExpTuple ")"
16                     | "[" ExpList "]"
17                     | "[" Exp OptExpComma ".." OptExp "]"
18                     | "[" Exp "|" Quals "]"
19                     | "(" InfixExp QOp ")"
20                     | "(" QOp InfixExp ")" //qop cannot be - (
                        minus) UNFINISHED
21                     //Liyi: place a check here to check
                        if QOp is a minus
22
23
24      syntax OptExpComma ::= "," Exp | "" [onlyLabel, klabel('
                        emptyExpComma)]
25      syntax OptExp ::= Exp | "" [onlyLabel, klabel('emptyExp)]
26
27      syntax ExpList ::= Exp | Exp "," ExpList [right]
28      syntax ExpTuple ::= Exp "," Exp [right, klabel('
                        twoExpTuple)]
29                      | Exp "," ExpTuple [right, klabel('
                        expTupleCon)]
30
31      //constr datatypes
32      syntax OptConstrs ::= "=" Constrs [klabel('nonemptyConstrs)
                        ] | "" [onlyLabel, klabel('emptyConstrs)]
33      syntax Constrs ::= Constr [klabel('singleConstr)] |
                        Constr "|" Constrs [klabel('multConstr)]
34      syntax Constr ::= Con OptBangATypes [klabel('constrCon)
                        ] // (arity con = k, k 0) UNFINISHED
35                      | SubConstr ConOp SubConstr

```

```
36             | Con "{" FieldDeclList "}"
37
38   syntax NewConstr  ::= Con AType [klabel('newConstrCon)]
39             | Con "{" Var ":" Type "}"
40
41   syntax SubConstr   ::= BType | "!" AType
42   syntax FieldDeclList ::= List{FieldDecl, ","}
43   syntax FieldDecl  ::= VarsType
44             | Vars ":" "!" AType
45
46
47   syntax OptBangATypes ::= List{OptBangAType, " "} [klabel('
      optBangATypes)]
48   syntax OptBangAType ::= OptBang AType [klabel('optBangAType)
      ]
49   syntax OptBang ::= "!" | "" [onlyLabel, klabel('emptyBang)]
50
51   syntax OptContext ::= Context "=>" | "" [onlyLabel, klabel('
      emptyContext)]
52   syntax Context ::= Class
53             | "(" Classes ")"
54
55   syntax Classes ::= List{Class, ","}
56
57   syntax SimpleClass ::= QTyCon TyVar [klabel('classCon)]
58
59   syntax Class      ::= SimpleClass
60             | QTyCon "(" TyVar ATypeList ")"
61             //Liyi: a check in preprocessing to
62             //check if the Atype list is
63             //empty
64             //it must have at least one item
65
66   //define type and simple type
67   syntax SimpleType ::= TyCon TyVars [klabel('simpleTypeCon)
      ]
68   syntax Type ::= BType
69             | BType "->" Type [klabel('typeArrow)]
70
71   syntax BType ::= AType
72             | BType AType [klabel('baTypeCon)]
73
74   syntax ATypeList ::= List{AType, ""} [klabel('atypelist)]
```

```

73     syntax AType ::= GTyCon                                [klabel('
        atypeGTyCon)]
74         | TyVar                                           [klabel('
        atypeTyVar)]
75         | "(" TypeTuple ")"                               [klabel('
        atypeTuple)]
76         | "[" Type "]"                                     [klabel('tyList)
        ]
77         | "(" Type ")"                                     [bracket]
78     syntax TypeTuple ::= Type "," Type                    [right,klabel('
        twoTypeTuple)]
79         | Type "," TypeTuple                             [klabel('
        typeTupleCon)]
80     syntax Types ::= List{Type, ","}
81
82     syntax GConCommas ::= "," | "," GConCommas
83     syntax GConCommon ::= "(" | "[" | "(" GConCommas ")" //was
        incorrect syntax
84     syntax GTyCon ::= QTyCon
85         | GConCommon
86         | "(->)"
87
88     syntax GCon ::= GConCommon
89         | QCon
90
91     //inst definition
92     syntax Inst ::= GTyCon
93         | "(" GTyCon TyVars ")" //TyVars must be
        distinct UNFINISHED
94         | "(" TyVarTuple ")" //TyVars must be
        distinct
95         | "[" TyVar "]" [klabel('tyVarList)]
96         | "(" TyVar "->" TyVar ")" //TyVars must be
        distinct
97     //pat definition
98     syntax Pat ::= LPat QConOp Pat
99         | LPat
100
101     syntax LPat ::= APat
102         | "-" IntFloat [klabel('minusPat)]
103         | GCon APatList [klabel('lpatCon)]//arity
        gcon = k UNFINISHED
104

```

```
105     syntax APatList ::= APat | APat APatList [klabel('apatCon)]
106
107     syntax APat ::= Var [klabel('apatVar)]
108                   | Var "@" APat
109                   | GCon
110                   | QCon "{" FPats "}"
111                   | Literal [klabel('apatLiteral)]
112                   | "_"
113                   | "(" Pat ")" [bracket]
114                   | "(" PatTuple ")"
115                   | "[" PatList "]"
116                   | "~" APat
117
118     syntax PatTuple ::= Pat "," Pat [klabel('twoPatTuple
119                               )]
120                               | Pat "," PatTuple [klabel('patTupleCon
121                               )]
122
123     syntax PatList ::= Pat
124                   | Pat "," PatList [klabel('patListCon)
125                   ]
126
127     //definition of quals
128     syntax Quals ::= Qual | Qual "," Quals [klabel('qualCon)]
129
130     syntax Qual ::= Pat "<-" Exp
131                   | "let" Decls
132                   | Exp
133
134     //definition of alts
135     syntax Alts ::= Alt | Alt ";" Alts
136
137     syntax Alt ::= Pat "->" Exp [klabel('altArrow)]
138                   | Pat "->" Exp "where" Decls
139                   | "" [onlyLabel, klabel('emptyAlt)]
140
141     //definition of stmts
142     syntax StmtList ::= StmtList Exp OptSemicolon
143     syntax StmtList ::= List{Stmt, ""}
144     syntax Stmt ::= Exp ";"
145                   | Pat "<-" Exp ";"
```

```
145             | "let" Decls ";"  
146             | ";"  
147  
148     //definition of fbind  
149     syntax FBindList ::= List{FBind, ","}  
150     syntax FBind ::= QVar "=" Exp
```

APPENDIX B

HASKELL-CONFIGURATION.K

```
1 requires "haskell-syntax.k"
2
3 module HASKELL-CONFIGURATION
4     imports HASKELL-SYNTAX
5
6     syntax KItem ::= "startImportRecursion"
7     syntax KItem ::= callInit(K)
8     //syntax KItem ::= initPreModule(K) [function]
9     //syntax KItem ::= tChecker(K) [function]
10
11     configuration
12         <T>
13             <k> $PGM:ModuleList ~> startImportRecursion </k>
14             <tempModule> .K </tempModule>
15             <tempCode> .K </tempCode>
16             <typeIterator> 1 </typeIterator>
17             <tempAlpha> .K </tempAlpha>
18             <tempAlphaMap> .Map </tempAlphaMap>
19             <tempBeta> .Map </tempBeta>
20             <tempT> .K </tempT>
21             <tempDelta> .Map </tempDelta>
22             <tempAlphaStar> .K </tempAlphaStar>
23             <tempBetaStar> .K </tempBetaStar>
24             <importTree> .List </importTree>
25             <recurImportTree> .List </recurImportTree>
26             <impTreeVMap> .Map </impTreeVMap>
27             <modules> //static information about a module
28                 <module multiplicity="*">
29                     <moduleName> .K </moduleName>
30                     <moduleAlphaStar> .K </moduleAlphaStar>
31                     <moduleBetaStar> .K </moduleBetaStar>
32                     <moduleImpAlphas> .List </moduleImpAlphas>
33                     <moduleImpBetas> .List </moduleImpBetas>
```

```
34          <moduleCompCode> .K </moduleCompCode>
35          <moduleTempCode> .K </moduleTempCode>
36          <imports> .Set </imports>
37          <classes> //static information about a
              module
38              <class multiplicity="*">
39                  <className> .K </className>
40              </class>
41          </classes>
42      </module>
43  </modules>
44  </T>
45
46 endmodule
```

APPENDIX C

HASKELL-PREPROCESSING.K

```
1 //
2 requires "haskell-syntax.k"
3 requires "haskell-configuration.k"
4
5 module HASKELL-PREPROCESSING
6     imports HASKELL-SYNTAX
7     imports HASKELL-CONFIGURATION
8
9     //USER DEFINED LIST
10    //definition of ElemList
11
12    //syntax KItem ::= ElemList
13    syntax ElemList ::= List{Element, ",", ""} [strict]
14    //    syntax Int ::= lengthOfList(ElemList) [function]
15
16    //    rule lengthOfList(.ElemList) => 0
17    //    rule lengthOfList(val(K:K),L:ElemList) => 1 +Int
18    //    rule lengthOfList(valValue(K:K),L:ElemList) => 1 +Int
19    //    lengthOfList(L)
20
21    syntax Element ::= val(K) [strict]
22    syntax ElementResult ::= valValue(K)
23    syntax Element ::= ElementResult
24    syntax KResult ::= ElementResult
25    rule val(K:KResult) => valValue(K) [structural]
26
27    //form ElemList
28    //    syntax ElemList ::= formElemList(K) [function]
29
30    //CONVERT ~> TO List
31    //list convert
32    //    syntax List ::= convertToList(K) [function]
```

```
32 //      rule convertToList(.K) => .List
33 //      rule convertToList(A:KItem ~> B:K) => ListItem(A)
      convertToList(B)
34
35
36      syntax KItem ::= dealWithImports(K,K)
37
38      rule <k> 'modListSingle('module(A:K,, B:K)) =>
      dealWithImports(A,B) ...</k>
39
40      (.Bag =>
41          <module>...    //DOT DOT DOT MEANS OVERWRITE ONLY SOME
      OF THE DEFAULTS
42          <moduleName> A </moduleName>
43          ...</module>
44      )
45
46      rule <k> 'modList('module(A:K,, B:K),, C:K) =>
      dealWithImports(A,B) ~> C ...</k>
47
48      (.Bag =>
49          <module>...    //DOT DOT DOT MEANS OVERWRITE ONLY SOME
      OF THE DEFAULTS
50          <moduleName> A </moduleName>
51          ...</module>
52      )
53
54 //      rule dealWithImports(Mod:K, A:K) => callInit(A)
55
56 //      rule <k> dealWithImports(Mod:K, A:K) => callInit(A) ...</k>
      >
57
58      rule <k> dealWithImports(Mod:K, 'bodyimpandtop(A:K,, B:K))
      => .K ...</k>
59      <importTree> L:List => L importListConvert(Mod, A) </
      importTree>
60      <recurImportTree> L:List => L importListConvert(Mod, A)
      </recurImportTree>
61
62      <moduleName> Mod </moduleName>
63      <imports> S:Set (.Set => SetItem(A)) </imports>
64      <moduleTempCode> OldTemp:K => B </moduleTempCode>
65
```

```
66     rule <k> dealWithImports (Mod:K, 'bodyimpdecls (A:K)) => .K
        ...</k>
67     <importTree> L:List => L importListConvert (Mod, A) </
        importTree>
68     <recurImportTree> L:List => L importListConvert (Mod, A)
        </recurImportTree>
69
70     <moduleName> Mod </moduleName>
71     <imports> S:Set (.Set => SetItem(A)) </imports>
72
73 //     rule <k> dealWithImports (Mod:K, 'bodytopdecls (A:K)) =>
        callInit(A) ...</k>
74     rule <k> dealWithImports (Mod:K, 'bodytopdecls (B:K)) => .K
        ...</k>
75
76     <moduleName> Mod </moduleName>
77     <moduleTempCode> OldTemp:K => B </moduleTempCode>
78
79     //importlist convert
80     syntax List ::= importListConvert (K,K) [function]
81     syntax KItem ::= impObject (K,K)
82
83     rule importListConvert (Name:K, 'impDecl (A:K,, Rest:K)) =>
        importListConvert (Name, A) importListConvert (Name, Rest)
84     rule importListConvert ('moduleName (Name:K), 'impDecl (A:K,,
        Modid:K,, C:K,, D:K)) => ListItem (impObject (Name, Modid))
85     rule importListConvert (Name:K, .ImpDecl) => .List
86
87 //////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
88
89     /*NEW TODO ALGORITHM
90     1. Construct tree for module inclusion
91     2. Check tree for cycles
92     3. Go to each leaf and recursively go up the tree and build
        alpha* and beta* for the types of the module and the children
93     (and specify scoping) (desugar the scope so that each type
        specifies the scope) */
94
95     syntax KItem ::= "checkImportCycle"
96     syntax KItem ::= "recurseImportTree"
97
98 /*     rule <k> performNextChecks
```

```

99         => checkUseVars
100         ~> (checkLabelUses
101         ~> (checkBlockAddress(.K)
102         ~> (checkNoNormalBlocksHavingLandingpad(.K, TNS
            -Set TES)
103         ~> (checkAllExpBlocksHavingLandingpad(.K, TES)
104         ~> (checkAllExpInFromInvoke(.K, TES)
105         ~> (checkLandingpad
106         ~> checkLandingDomResumes)))))) ...</k> */
107
108 rule <k> startImportRecursion => checkImportCycle
109         ~> (recurseImportTree)...</
            k>
110
111 syntax KItem ::= cycleCheck(K,Map,List,List) [function] //
            current node, map of all nodes to visited or not, stack,
            graph
112 syntax Map ::= createVisitMap(List,Map) [function] //graph,
            visitmap
113 syntax KItem ::= getUnvisitedNode(K,K, Map) [function] //
            visitmap
114 syntax List ::= getNodeNeighbors(K,List) [function] //
            visitmap
115
116 rule <k> checkImportCycle
117     => cycleCheck(.K,createVisitMap(I, .Map),.List,I)
            ...</k>
118     <importTree> I:List </importTree>
119     <impTreeVMap> .Map => createVisitMap(I, .Map) </
            impTreeVMap>
120
121 syntax KItem ::= "visited"
122 syntax KItem ::= "unvisited"
123 syntax KItem ::= "none"
124
125 rule createVisitMap(ListItem(impObject(A:K,B:K)) Rest:List,
            M:Map)
126     => createVisitMap(Rest, M[A <- unvisited][B <-
            unvisited])
127 rule createVisitMap(.List, M:Map) => M
128
129 rule getUnvisitedNode(.K, .K, .Map) => none
130 rule getUnvisitedNode(.K, .K, (A:K |-> B:K) M:Map)
```

```
131         => getUnvisitedNode(A, B, M)
132 rule getUnvisitedNode(A:KItem, unvisited, M:Map) => A
133 rule getUnvisitedNode(A:KItem, visited, M:Map)
134     => getUnvisitedNode(.K, .K, M)
135
136
137
138 rule getNodeNeighbors(Node:K, .List) => .List
139 rule getNodeNeighbors(.K, Rest:List) => .List
140
141 rule getNodeNeighbors(Node:KItem, ListItem(impObject(Node,B:
142     KItem)) Rest:List) => getNodeNeighbors(Node, Rest)
143     ListItem(B)
144 rule getNodeNeighbors(Node:KItem, ListItem(impObject(A:KItem,
145     B:KItem)) Rest:List) => getNodeNeighbors(Node, Rest)
146     requires Node !=K A
147
148 rule cycleCheck(none, M:Map, .List, L:List) => .K
149 rule cycleCheck(.K, M:Map, .List, I:List) => cycleCheck(
150     getUnvisitedNode(.K, .K, M), M, .List, I)
151 rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:List)
152     => cycleCheck(Node, M, S, I)
153 rule cycleCheck(Node:K, M:Map, S:List, I:List)
154     => cycleCheck(.K, M[Node <- visited],
155         getNodeNeighbors(Node,I) S, I)
156     requires Node !=K .K andBool Node !=K none
157 rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:K) =>
158     cycleCheck(Node, M, S, I)
159     requires S !=K .List
160
161 /*
162 rule cycleCheck(A:K, .K, .K, I:K) => cycleCheck(A,
163     createVisitMap(I, .Map), .List, I)
164
165
166 rule cycleCheck(Node:K, M:Map, S:List, I:K) => cycleCheck(.K
167     , M[Node <- visited], getNodeNeighbors(Node,I) S, I)
168
169 rule cycleCheck(.K, M:Map, ListItem(Node:K) S:List, I:K) =>
170     cycleCheck(Node, M, S, I)
```

```
163      //rule cycleCheck(.K, M:Map, .K, ListItem(impObject(A:K,B:K)
          ) Rest:List) => cycleCheck(ListItem(impObject(A:K,B:K))
          Rest:List)
164 */
165
166 //////////////////////////////////////
167
168 //COPY IMPORT GRAPH, NEED SECOND GRAPH FOR RECURSING, ADDITIONAL
    GRAPH FOR SELECTING IMPORTS FOR ALPHA* AND BETA*
169 //DFS for leaf
170 //acquire alpha and beta for leaf
171 //merge alpha and beta with imports to produce alpha* and beta*
172 //perform checks
173 //perform inferencing
174 //insert alpha* and beta* into importing modules
175 //remove all edges pointing to leaf
176
177     syntax KItem ::= "leafDFS"
178     syntax KItem ::= "getAlphaAndBeta"
179     syntax KItem ::= "getAlphaBetaStar"
180     syntax KItem ::= "performIndividualChecks"
181     syntax KItem ::= "performIndividualInferencing"
182     syntax KItem ::= "insertAlphaBetaStar"
183     syntax KItem ::= "removeAllEdges"
184     syntax KItem ::= "seeIfFinished"
185
186     rule <k> recurseImportTree => leafDFS
187                               ~> (getAlphaAndBeta
188                               //~> (getAlphaBetaStar
189                               ~> (
                                   performIndividualInferencing
                                   ))...</k>
190
191 //rule <k> dealWithImports (Mod:K, 'bodytopdecls(A:K)) =>
    callInit(A) ...</k>
192
193 //     rule <k> leaf
194 //           => cycleCheck(.K,createVisitMap(I, .Map),.List,I)
    ...</k>
195 //     <importTree> I:List </importTree>
196
```

```

197 //////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
198
199   syntax KItem ::= returnLeafDFS(K,List,Map) [function] //
        current node, map of all nodes to visited or not, stack,
        graph
200   syntax KItem ::= innerLeafDFS(K,List) [function]
201   syntax KItem ::= loadModule(K)
202
203   rule <k> leafDFS
204       => returnLeafDFS(.K,I,M) ...</k>
205       <recurImportTree> I:List </recurImportTree>
206       <impTreeVMap> M:Map </impTreeVMap>
207
208   rule returnLeafDFS(.K,ListItem(impObject(Node:KItem,B:KItem)
        ) I:List,M:Map) => returnLeafDFS(B,I,M)
209   rule returnLeafDFS(Node:KItem,I:List,M:Map) => returnLeafDFS
        (innerLeafDFS(Node,I),I,M)
210       requires innerLeafDFS(Node,I) !=K none
211   rule returnLeafDFS(Node:KItem,I:List,M:Map) => loadModule(
        Node)
212       requires innerLeafDFS(Node,I) ==K none
213
214   rule innerLeafDFS(Node:KItem,ListItem(impObject(Node,B:KItem
        )) I:List) => B
215   rule innerLeafDFS(Node:KItem,ListItem(impObject(A:KItem,B:
        KItem)) I:List) => innerLeafDFS(Node,I)
216       requires Node !=K A
217   rule innerLeafDFS(Node:KItem,.List) => none
218 //   returnLeafDFS(Node:KItem,ListItem(impObject(Node,B:KItem))
        I:List,M:Map) => returnLeafDFS(B,I,M)
219
220
221 //////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
222
223   //call before Checker Code
224 //   rule <k> callInit(S:K) => initPreModule(S) ...</k>
225 //       <tempModule> A:K => S </tempModule>
226
227   rule <k> loadModule(S:KItem) => .K ...</k>
228       <tempModule> A:K => S </tempModule>
229

```

```

230 rule <k> getAlphaAndBeta => initPreModule(Code) ...</k>
231     <tempModule> Mod:KItem </tempModule>
232
233     <moduleName> 'moduleName (Mod) </moduleName>
234     <moduleTempCode> Code:KItem </moduleTempCode>
235
236
237 //////////////////////////////////////
238
239 //get alpha and beta
240 syntax KItem ::= Module(K, K)
241 syntax KItem ::= preModule(K,K) //(alpha, T)
242
243 // STEP 1 CONSTRUCT T AND ALPHA
244 // alpha = type
245 // T = newtype and data, temporary data structure
246
247 syntax KItem ::= initPreModule(K) [function]
248 syntax KItem ::= getPreModule(K, K) [function] //(Current
249     term, premodule)
250 syntax KItem ::= makeT (K,K,K,K)
251
252 syntax KItem ::= fetchTypes (K,K,K,K)
253
254 syntax List ::= makeInnerT (K,K,K) [function] //LIST
255 syntax List ::= getTypes(K) [function] //LIST
256
257 syntax KItem ::= getCon(K) [function]
258 syntax List ::= getArgSorts(K) [function] //LIST
259
260 syntax KItem ::= AList(K)
261 syntax KItem ::= AObject(K,K) //(1st -> 2nd) map without
262     idempotency
263 syntax KItem ::= ModPlusType(K,K)
264
265 syntax KItem ::= TList(K) //list of T objects for every new
266     type introduced by data and newtype
267 syntax KItem ::= TObject(K,K,K,K) //(module name, type name,
268     entire list of poly type vars, list of inner T pieces)
269 syntax KItem ::= InnerTPiece(K,K,K,K,K) //(type constructor,
270     poly type vars, argument sorts, entire constr block,
271     type name)
272

```



```

266 //      rule initPreModule('module(I:ModuleName,, J:K)) =>
      getPreModule(J,preModule(AList(.List),TList(.List)))
267 //      rule initPreModule('moduleExp(I:ModuleName,, L:K,, J:K))
      => getPreModule(J,preModule(AList(.List),TList(.List)))
268 //      rule initPreModule('moduleBody(J:Body)) => getPreModule(J,
      preModule(AList(.List),TList(.List)))
269
270      rule initPreModule(J:K) => getPreModule(J,preModule(AList(.
      List),TList(.List)))
271
272      rule getPreModule('bodytopdecls(I:K), J:K) => getPreModule(I
      ,J)
273      rule getPreModule('topdeclslist('type(A:K,, B:K),, Rest:K),J
      :K) => fetchTypes(A,B,Rest,J) //constructalpha
274
275
276      rule getPreModule('topdeclslist('data(A:K,, B:K,, C:K,, D:K)
      ,, Rest:K),J:K) => makeT(B,C,Rest,J)
277      rule getPreModule('topdeclslist('newtype(A:K,, B:K,, C:K,, D
      :K),, Rest:K),J:K) => makeT(B,C,Rest,J)
278
279
280      rule getPreModule('topdeclslist('topdecldecl(A:K),, Rest:K),
      J:K) => getPreModule(Rest,J)
281      rule getPreModule('topdeclslist('class(A:K,, B:K,, C:K,, D:K
      ),, Rest:K),J:K) => getPreModule(Rest,J)
282      rule getPreModule('topdeclslist('instance(A:K,, B:K,, C:K,,
      D:K),, Rest:K),J:K) => getPreModule(Rest,J)
283      rule getPreModule('topdeclslist('default(A:K,, B:K,, C:K,, D
      :K),, Rest:K),J:K) => getPreModule(Rest,J)
284      rule getPreModule('topdeclslist('foreign(A:K,, B:K,, C:K,, D
      :K),, Rest:K),J:K) => getPreModule(Rest,J)
285      rule getPreModule(.TopDecls,J:K) => J
286
287      //rule getPreModule('module(I:ModuleName,L:K, J:K)) =>
      preModule(J)
288
289      rule <k> fetchTypes('simpleTypeCon(I:TyCon,, H:TyVars), '
      atypeGTyCon(C:K), Rest:K, preModule(AList(M:List), L:K))
      => getPreModule(Rest,preModule(AList(ListItem(AObject(
      ModPlusType(ModName,I),C)) M), L)) ...</k>
290      <tempModule> ModName:KItem </tempModule>
291

```

```

292     rule <k> makeT('simpleTypeCon(I:TyCon,, H:TyVars), D:K, Rest
      :K, preModule(AList(M:List), TList(ListInside:List))) =>
      getPreModule(Rest,preModule(AList(M),TList(ListItem(
      TObject(ModName,I,H,makeInnerT(I,H,D))) ListInside)))
      ...</k>
293     <tempModule> ModName:KItem </tempModule>
294
295     rule makeInnerT(A:K,B:K,'nonemptyConstrs(C:K)) => makeInnerT
      (A,B,C)
296     rule makeInnerT(A:K,B:K,'singleConstr(C:K)) => ListItem(
      InnerTPiece(getCon(C),getTypeVars(C),getArgSorts(C),C,A))
297     rule makeInnerT(A:K,B:K,'multConstr(C:K,, D:K)) => ListItem(
      InnerTPiece(getCon(C),getTypeVars(C),getArgSorts(C),C,A))
      makeInnerT(A,B,D)
298
299     rule getTypeVars('constrCon(A:K,, B:K)) => getTypeVars(B)
300     rule getTypeVars('optBangATypes(A:K,, Rest:K)) =>
      getTypeVars(A) getTypeVars(Rest)
301     rule getTypeVars('optBangAType('emptyBang(.KList),, Rest:K))
      => getTypeVars(Rest)
302     rule getTypeVars('atypeGTyCon(A:K)) => .List
303     rule getTypeVars('atypeTyVar(A:K)) => ListItem(A)
304     rule getTypeVars(.OptBangATypes) => .List
305
306     //rule getCon('emptyConstrs()) => .K
307     //rule getCon('nonemptyConstrs(A:K)) => getCon(A)
308     rule getCon('constrCon(A:K,, B:K)) => A
309
310     //rule getArgSorts('constrCon(A:K,, B:K)) => B
311     rule getArgSorts('constrCon(A:K,, B:K)) => getArgSorts(B)
312     rule getArgSorts('optBangATypes(A:K,, Rest:K)) =>
      getArgSorts(A) getArgSorts(Rest)
313     rule getArgSorts('optBangAType('emptyBang(.KList),, Rest:K))
      => getArgSorts(Rest)
314     rule getArgSorts('atypeGTyCon(A:K)) => ListItem(A)
315     rule getArgSorts('atypeTyVar(A:K)) => .List
316     rule getArgSorts(.OptBangATypes) => .List
317
318     //////////////////////////////////////
319
320     rule <k> preModule(A:K,T:K) => startTTransform ...</k>
321     <tempAlpha> OldAlpha:K => A </tempAlpha>

```

```

322      <tempT> OldT:K => T </tempT>
323
324  //////////////////////////////////////
325
326  // STEP 2 PERFORM CHECKS
327
328  syntax KItem ::= "error"
329
330  syntax KItem ::= "startChecks"
331  syntax KItem ::= "checkNoSameKey"
332      //Keys of alpha and keys of T should be unique
333  syntax KItem ::= "checkTypeConsDontCollide"
334      //Make sure typeconstructors do not collide in T
335  syntax KItem ::= "makeAlphaMap"
336      //make map for alpha
337  syntax KItem ::= "checkAlphaNoLoops"
338      //alpha check for no loops
339      //check alpha to make sure that everything points to a T
340  syntax KItem ::= "checkArgSortsAreTargets"
341      //Make sure argument sorts [U] [W,V] are in the set
342      of keys of alpha and targets of T, (keys of T)
343  syntax KItem ::= "checkParUsed"
344  //NEED TO CHECK all the polymorphic parameters from right appear
345  on left. RIGHT SIDE ONLY
346  //NEED TO CHECK UNIQUENESS FOR POLY PARAM ON LEFT SIDE ONLY
347
348  //      rule <k> preModule(A:K,T:K) => startChecks ...</k>
349  //      <tempAlpha> OldAlpha:K => A </tempAlpha>
350  //      <tempT> OldT:K => T </tempT>
351
352  /*      rule <k> performNextChecks
353          => checkUseVars
354              ~> (checkLabelUses
355                  ~> (checkBlockAddress(.K)
356                      ~> (checkNoNormalBlocksHavingLandingpad(.K, TNS
357                          -Set TES)
358                          ~> (checkAllExpBlocksHavingLandingpad(.K, TES)
359                              ~> (checkAllExpInFromInvoke(.K, TES)
360                                  ~> (checkLandingpad
361                                      ~> checkLandingDomResumes)))))) ...</k> */

```

```

361     rule <k> startChecks
362         => checkNoSameKey
363         ~> (checkTypeConsDontCollide
364             ~> (makeAlphaMap
365                 ~> (checkAlphaNoLoops
366                     ~> (checkArgSortsAreTargets
367                         ~> (checkParUsed)))) ...</k>
368
369     rule <k> checkTypeConsDontCollide
370         => tyConCollCheck(T,.List,.Set) ...</k>
371         <tempT> T:K </tempT>
372
373     //syntax KItem ::= tChecker(K) [function]
374     syntax KItem ::= tyConCollCheck(K,K,K) [function] //(TList,
375         List of Tycons,Set of Tycons)
376     syntax KItem ::= lengthCheck(K,K) [function]
377     //syntax KItem ::= tyConCollCheck(K,K,K) [function]
378     //syntax K ::= innerCollCheck(K) [function]
379     //syntax K ::= tyConCollCheckPasser(K, K) [function]
380
380     //rule tChecker(preModule(Alpha:Map,T:K,Mod:K)) =>
381         tyConCollCheck(innerCollCheck(T),preModule(Alpha,T,Mod))
382
382     //rule tyConCollCheck(.K,preModule(Alpha:Map,H:K,Mod:K)) =>
383         tyConCollCheck(innerCollCheck(H),preModule(Alpha,H,Mod))
384
384     rule tyConCollCheck(TList(ListItem(TObject(ModName:K, A:K,B:
385         K,ListItem(InnerTPiece(Ty:K,E:K,F:K,H:K,G:K)) Inners:List
386         )) Rest:List),J:Set,D:Set) =>
387         tyConCollCheck(TList(ListItem(TObject(
388             ModName,A,B,Inners)) Rest),ListItem(Ty) J
389             , SetItem(Ty) D)
390
390     rule tyConCollCheck(TList(ListItem(TObject(ModName:K, A:K,B:
391         K,.List)) Rest:List),J:Set,D:Set) =>
392         tyConCollCheck(TList(Rest),J,D)
393
393     rule tyConCollCheck(TList(.List),J:Set,D:Set) =>
394         lengthCheck(size(J),size(D))
395
395     rule lengthCheck(A:Int, B:Int) => .K
396         requires A ==Int B
397
397     rule lengthCheck(A:Int, B:Int) => error
398         requires A /=Int B

```

```

396
397 //rule tyConCollCheck(TList(TObject(A:K,B:K,C:K) ~> Rest:K),
      J:K) => tyConCollCheckPasser(TList(innerCollCheck(TObject
      (A:K,B:K,C:K)) ~> Rest:K),J:K)
398 syntax KItem ::= keyCheck(K,K,K,K) [function] //(Alpha, T,
      List of names, Set of names)
399
400 rule <k> checkNoSameKey
401     => keyCheck(A, T, .Set, .List) ...</k>
402     <tempAlpha> A:K </tempAlpha>
403     <tempT> T:K </tempT>
404 //rule <k> checkAlphaNoSameKey
405 //     => akeyCheck(.K, .Set) ...</k>
406
407 rule keyCheck(AList(ListItem(AObject(A:K,B:K)) C:List), T:K,
      D:Set, G:List) => keyCheck(AList(C), T, SetItem(A) D,
      ListItem(A) G)
408 rule keyCheck(AList(.List), TList(ListItem(TObject(ModName:K
      , A:K,B:K,C:K)) Rest:List), D:Set, G:List) => keyCheck(
      AList(.List), TList(Rest), SetItem(A) D, ListItem(A) G)
409 rule keyCheck(AList(.List), TList(.List), D:Set, G:List) =>
      lengthCheck(size(G),size(D))
410
411
412 syntax KItem ::= makeAlphaM(K,K) [function] //(Alpha,
      AlphaMap)
413 syntax KItem ::= tAlphaMap(K) //(AlphaMap) temp alphamap
414
415 rule <k> makeAlphaMap
416     => makeAlphaM(A, .Map) ...</k>
417     <tempAlpha> A:K </tempAlpha>
418
419 rule makeAlphaM(AList(ListItem(AObject(A:K,B:K)) C:List), M:
      Map) => makeAlphaM(AList(C), M[A <- B])
420 rule makeAlphaM(AList(.List), M:Map) => tAlphaMap(M)
421
422 rule <k> tAlphaMap(M:K) => .K ...</k>
423     <tempAlphaMap> OldAlphaMap:K => M </tempAlphaMap>
424
425 // syntax KItem ::= tkeyCheck(K,K,K) [function] //(T,List of
      T,Set of T)
426
427 // rule <k> checkTNoSameKey

```

```

428 //          => tkeyCheck(T, .Set, T) ...</k>
429 //          <tempT> T:K </tempT>
430
431 //      rule tkeyCheck(TList(ListItem(TObject(A:K,B:K,C:K)) Rest:
List), D:Set, G:K) => tkeyCheck(TList(Rest), SetItem(A) D, G)
432 //      rule tkeyCheck(TList(.List), D:Set, TList(G:List)) =>
lengthCheck(size(G),size(D))
433
434      syntax KItem ::= aloopCheck(K,K,K,K,K,K,K) [function] //(
      Alpha,List of Alpha,Set of Alpha,CurrNode,lengthcheck,T,
      BigSet)
435
436      rule <k> checkAlphaNoLoops
437          => aloopCheck(A,.List,.Set,.K,.K,T,.Set) ...</k>
438          <tempAlphaMap> A:K </tempAlphaMap>
439          <tempT> T:K </tempT>
440
441      //aloopCheck set and list to check cycles
442      rule aloopCheck(Alpha:Map (A:KItem |-> B:KItem), D:List, G:
Set, .K, .K,T:K,S:Set) => aloopCheck(Alpha, ListItem(B)
      ListItem(A) D, SetItem(B) SetItem(A) G, B, .K,T,S)
443      rule aloopCheck(Alpha:Map (H |-> B:KItem), D:List, G:Set, H:
KItem, .K,T:K,S:Set) => aloopCheck(Alpha, ListItem(B) D,
      SetItem(B) G, B, .K,T,S)
444
445      rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K,T:K,S:
Set) => aloopCheck(Alpha, .List, .Set, .K, lengthCheck(
      size(G),size(D)),T,G S) //type rename loop ERROR
446          requires (notBool H in keys(Alpha)) andBool (H in
      typeSet(T, .Set) orBool H in S)
447
448      rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K,T:K,S:
Set) => error //terminal alpha rename is not in T ERROR
449          requires (notBool H in keys(Alpha)) andBool (notBool (H
      in typeSet(T, .Set) orBool H in S))
450
451
452      syntax Set ::= typeSet(K,K) [function] //(K, KSet)
453      rule typeSet(TList(ListItem(TObject(ModName:K, A:K,B:K,C:K))
      Rest:List), D:Set) => typeSet(TList(Rest), SetItem(A) D)
454      rule typeSet(TList(.List), D:Set) => D
455

```

```
456 //      rule aloopCheck(Alpha:Map, D:List, G:Set, H:KItem, .K) =>
      keys(Alpha) ~> H
457 //          requires notBool H in keys(Alpha)
458
459      rule aloopCheck(.Map, .List, .Set, .K, .K,T:K, S:Set) => .K
460 //      rule aloopCheck(AList(Front:List ListItem(AObject(H,B:K))
      C:List), D:List, G:Set, H:ConId) => aloopCheck(AList(C:List),
      ListItem(B) D, SetItem(B) G, B)
461
462
463 //      syntax KItem ::= TList(K) //list of T objects for every
      new type introduced by data and newtype
464 //      syntax KItem ::= TObject(K,K,K) //(type name, entire list
      of poly type vars, list of inner T pieces)
465 //      syntax KItem ::= InnerTPiece(K,K,K,K,K) //(type
      constructor, poly type vars, argument sorts, entire constr
      block, type name)
466
467 //Make sure argument sorts [U] [W,V] are in the set of keys of
      alpha and targets of T, (keys of T)
468
469      syntax KItem ::= argSortCheck(K,K,K) [function] //(T,
      AlphaMap)
470
471      rule <k> checkArgSortsAreTargets
472          => argSortCheck(T,A,typeSet(T,.Set)) ...</k>
473          <tempAlphaMap> A:K </tempAlphaMap>
474          <tempT> T:K </tempT>
475
476      rule argSortCheck(TList(ListItem(TObject(ModName:K, A:K,B:K,
      ListItem(InnerTPiece(C:K,D:K,ListItem(Arg:KItem) ArgsRest
      :List,E:K,F:K)) InnerRest:List)) TListRest:List),AlphaMap
      :Map,Tset:Set) => argSortCheck(TList(ListItem(TObject(
      ModName,A,B,ListItem(InnerTPiece(C,D,ArgsRest,E,F))
      InnerRest)) TListRest),AlphaMap,Tset)
477          requires ((Arg in keys(AlphaMap)) orBool (Arg in Tset))
478
479      rule argSortCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,D:K,ListItem(Arg:KItem) ArgsRest
      :List,E:K,F:K)) InnerRest:List)) TListRest:List),AlphaMap
      :Map,Tset:Set) => error
480          requires (notBool ((Arg in keys(AlphaMap)) orBool (Arg
      in Tset)))
```

```

481
482     rule argSortCheck (TList (ListItem (TObject (ModName:K, A:K, B:K,
      ListItem (InnerTPiece (C:K, D:K, .List, E:K, F:K)) InnerRest:
      List)) TListRest:List), AlphaMap:Map, Tset:Set) =>
      argSortCheck (TList (ListItem (TObject (ModName, A, B, InnerRest
      )) TListRest), AlphaMap, Tset)
483
484     rule argSortCheck (TList (ListItem (TObject (ModName:K, A:K, B:K, .
      List)) TListRest:List), AlphaMap:Map, Tset:Set) =>
      argSortCheck (TList (TListRest), AlphaMap, Tset)
485
486     rule argSortCheck (TList (.List), AlphaMap:Map, Tset:Set) => .K
487
488 //NEED TO CHECK all the polymorphic parameters from right appear
      on left. RIGHT SIDE ONLY
489 //NEED TO CHECK UNIQUENESS FOR POLY PARAM ON LEFT SIDE ONLY
490
491     syntax KItem ::= parCheck (K, K) [function] // (T, AlphaMap)
492     syntax KItem ::= makeTyVarList (K, K, K) [function] // (TyVars,
      NewList)
493     syntax KItem ::= lengthRet (K, K, K) [function]
494
495     rule <k> checkParUsed
496         => parCheck (T, .K) ...</k>
497     <tempT> T:K </tempT>
498
499 //rule makeParLists (TList (ListItem (TObject (A:K, ListItem (Arg:
      KItem) PolyList:List, C:K)) Rest:List), Tlist:List, Tset:Set
      ) => makeParLists (TList (ListItem (TObject (A, PolyList, C))
      Rest), ListItem (Arg) Tlist, SetItem (Arg) Tset)
500     rule parCheck (TList (ListItem (TObject (ModName:K, A:K, B:K, C:K))
      Rest:List), .K) => parCheck (TList (ListItem (TObject (
      ModName, A:K, B:K, C:K)) Rest:List), makeTyVarList (B, .List, .
      Set))
501
502     rule parCheck (TList (ListItem (TObject (ModName:K, A:K, B:K,
      ListItem (InnerTPiece (C:K, ListItem (Par:KItem) ParRest:List
      , D:K, E:K, F:K)) InnerRest:List)) Rest:List), NewSet:Set) =>
503     parCheck (TList (ListItem (TObject (ModName, A, B, ListItem (
      InnerTPiece (C, ParRest, D, E, F)) InnerRest)) Rest),
      NewSet)
504     requires Par in NewSet
505

```



```
506     rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,ListItem(Par:KItem) ParRest:List
      ,D:K,E:K,F:K)) InnerRest:List)) Rest:List),NewSet:Set) =>
      error
507         requires notBool (Par in NewSet)
508
509     rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,.List,D:K,E:K,F:K)) InnerRest:
      List)) Rest:List),NewSet:Set) =>
510         parCheck(TList(ListItem(TObject(ModName:A,B,InnerRest))
      Rest),NewSet)
511
512     rule parCheck(TList(ListItem(TObject(ModName:K,A:K,B:K,.List
      )) Rest:List),NewSet:Set) =>
513         parCheck(TList(Rest),NewSet)
514
515     rule parCheck(TList(.List),NewSet:Set) => .K
516
517     rule makeTyVarList('typeVars(A:K,,Rest:K),NewList:List,
      NewSet:Set) => makeTyVarList(Rest, ListItem(A) NewList,
      SetItem(A) NewSet)
518
519     rule makeTyVarList(.TyVars,NewList:List,NewSet:Set) =>
      lengthRet(size(NewList),size(NewSet),NewSet)
520
521     rule lengthRet(A:Int, B:Int, C:K) => C
522         requires A ==Int B
523
524     rule lengthRet(A:Int, B:Int, C:K) => error
525         requires A !=Int B
526
527     //rule argSortCheck(TList(ListItem(TObject(A:K,B:K,C:K)
528
529     //////////////////////////////////////
530
531     // STEP 3 Transform T into beta
532
533     syntax KItem ::= "startTTransform"
534     syntax KItem ::= "constructDelta"
535     syntax KItem ::= "constructBeta"
536
537     rule <k> startTTransform
```

```
538         => constructDelta
539         ~> (constructBeta) ...</k>
540
541     rule <k> constructDelta
542         => makeDelta(T, .Map) ...</k>
543     <tempT> T:K </tempT>
544
545     syntax KItem ::= makeDelta(K, Map) [function] //(T, Delta)
546     syntax KItem ::= newDelta(Map) //Delta
547     syntax KItem ::= newBeta(Map) //beta
548     syntax List ::= retPolyList(K, List) [function] //(T, Delta)
549
550     rule makeDelta(TList(ListItem(TObject(ModName:K, A:K, Polys:K,
551         C:K)) Rest:List), M:Map) =>
552         makeDelta(TList(Rest), M[ModPlusType(ModName, A) <- size(
553             retPolyList(Polys, .List))])
554     rule makeDelta(TList(.List), M:Map) => newDelta(M)
555
556     rule retPolyList('typeVars(A:K, , Rest:K), NewList:List) =>
557         retPolyList(Rest, ListItem(A) NewList)
558     rule retPolyList(.TyVars, L:List) => L
559
560     rule <k> newDelta(M:Map)
561         => .K ...</k>
562     <tempDelta> OldDelta:K => M </tempDelta>
563
564     rule <k> constructBeta
565         => makeBeta(T, .Map) ...</k>
566     <tempT> T:K </tempT>
567
568     syntax KItem ::= makeBeta(K, Map) [function] //(T, Beta, Delta)
569
570     rule makeBeta(TList(ListItem(TObject(ModName:K, A:K, B:K,
571         ListItem(InnerTPiece(Con:K, H:K, D:K, E:K, F:K)) InnerRest:
572         List)) Rest:List), Beta:Map) =>
573         makeBeta(TList(ListItem(TObject(ModName, A, B, InnerRest))
574             Rest), Beta[ModPlusType(ModName, Con) <- betaParser(E
575                 , B, A)])
576     rule makeBeta(TList(ListItem(TObject(ModName:K, A:K, B:K, .List
577         )) Rest:List), Beta:Map) =>
578         makeBeta(TList(Rest), Beta)
579     rule makeBeta(TList(.List), Beta:Map) =>
580         newBeta(Beta)
```

```
573 //      rule makeBeta(TList(ListItem(TObject(ModName:K,A:K,B:K,
      ListItem(InnerTPiece(C:K,H:K,D:K,E:K,F:K)) InnerRest:List))
      Rest:List),Beta:Map) =>
574 //      makeBeta(TList(ListItem(TObject(ModName,A,B,InnerRest
      )) Rest),Beta)
575
576      syntax KItem ::= betaParser(K,K,K) [function] //(Tree Piece,
      NewSyntax,Parameters,Constr)
577      syntax Set ::= getTyVarsRHS(K,List) [function]
578
579      syntax KItem ::= forAll(Set,K)
580      syntax KItem ::= funtype(K,K)
581
582      syntax Set ::= listToSet(List, Set) [function]
583
584      rule listToSet(ListItem(A:KItem) L:List, S:Set) => listToSet
      (L, SetItem(A) S)
585      rule listToSet(.List, S:Set) => S
586
587
588 //if optbangATypes, need to see if first variable is a typecon
589 //if its a typecon then need to go into Delta and see the amount
      of parameters it has
590 //then count the number of optbangATypes after the typecon
591      rule betaParser('constrCon(A:K,, B:K), Par:K, Con:K) =>
      forAll(getTyVarsRHS(B,.List), betaParser(B, Par, Con))
592      rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeTyVar(Tyv:K)),, Rest:K), Par:K, Con:K) =>
      funtype(Tyv, betaParser(Rest, Par, Con))
593      rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'baTypeCon(A:K,, B:K)),, Rest:K), Par:K, Con:K)
      => funtype('baTypeCon(A:K,, B:K), betaParser(Rest, Par,
      Con))
594      rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeGTyCon(Tyc:K)),, Rest:K), Par:K, Con:K) =>
      funtype(Tyc, betaParser(Rest, Par, Con))
595      rule betaParser(.OptBangATypes, Par:K, Con:K) => '
      simpleTypeCon(Con,, Par)
596 //      rule betaParser('optBangATypes('optBangAType('emptyBang(.
      KList),, 'atypeGTyCon(Tyc:K)),, Rest:KItem)) => getTypeVars(A
      ) getTypeVars(Rest)
597 //      rule getTypeVars('optBangAType('emptyBang(.KList),, Rest:K
      )) => getTypeVars(Rest)
```

```
598 //      rule getTypeVars(' atypeGTyCon(A:K)) => .List
599 //      rule getTypeVars(' atypeTyVar(A:K)) => ListItem(A)
600 //      rule getTypeVars(.OptBangATypes) => .List
601
602      rule getTyVarsRHS(.OptBangATypes, Tylist:List) => listToSet(
        Tylist, .Set)
603
604      rule <k> newBeta(M:Map)
605          => .K ...</k>
606          <tempBeta> OldBeta:K => M </tempBeta>
607
608 //////////////////////////////////////
609
610 //      syntax KItem ::= "insertAlphaBetaStar"
611
612      syntax KItem ::= insertABRec(K, List)
613      syntax KItem ::= insertAB(K)
614
615      rule <k> insertAlphaBetaStar => insertABRec(Mod, Imp) ...</k>
        >
616          <tempModule> Mod:KItem </tempModule>
617          <importTree> Imp:List </importTree>
618
619      rule <k> insertABRec(Node:KItem, ListItem(impObject(B:KItem,
        Node)) I:List) => insertAB(B) ~> insertABRec(Node, I)
        ...</k>
620
621      rule <k> insertABRec(Node:KItem, ListItem(impObject(B:KItem,
        C:KItem)) I:List) => insertABRec(Node, I) ...</k>
622          requires Node /=K C
623
624      rule <k> insertAB(B) => .K ...</k>
625
626          <tempAlphaStar> Alph:KItem </tempAlphaStar>
627          <tempBetaStar> Bet:KItem </tempBetaStar>
628
629          <moduleName> 'moduleName(B) </moduleName>
630          <moduleImpAlphas> ImpAlphas:List => ListItem(Alph)
        ImpAlphas </moduleImpAlphas>
631          <moduleImpBetas> ImpBetas:List => ListItem(Bet)
        ImpBetas </moduleImpBetas>
632
```

633

634 `endmodule`

APPENDIX D

HASKELL-TYPE-INFERENCING.K

```
1  requires "haskell-syntax.k"
2  requires "haskell-configuration.k"
3  requires "haskell-preprocessing.k"
4
5  module HASKELL-TYPE-INFERENCING
6      imports HASKELL-SYNTAX
7      imports HASKELL-CONFIGURATION
8      imports HASKELL-PREPROCESSING
9
10     syntax KItem ::= "Bool" //Boolean
11
12     // STEP 4 Type Inferencing
13     syntax KItem ::= inferenceShell(K) [function]//Input,
        AlphaMap, Beta, Delta, Gamma
14     //syntax KItem ::= typeInferenceFun(K,Map,Map,Map,Map,K,K) [
        function]//Input, Alpha, Beta, Delta, Gamma
15     //syntax KItem ::= typeInferenceFun(Map,K,K) //Gamma,
        Expression, Guessed Type
16     syntax Map ::= genGamma(K,Map,K) [function] //Apatlist,
        Gamma Type
17     syntax KItem ::= genLambda(K,K) [function]
18     syntax KItem ::= guessType(Int)
19 //     syntax KItem ::= lambdaReturn(K,K,K)
20     syntax KItem ::= freshInstance(K, Int) [function]
21     syntax Int ::= paramSize(K) [function]
22
23
24     syntax KItem ::= mapBag(Map)
25     syntax KResult ::= mapBagResult(Map)
26
27     syntax Map ::= gammaSub(Map,Map,Map) [function]//
        substitution, gamma
28
```

```

29     rule <k> performIndividualInferencing => inferenceShell(Code
30         ) ...</k>
31         <tempModule> Mod:KItem </tempModule>
32         <moduleName> 'moduleName(Mod) </moduleName>
33         <moduleTempCode> Code:KItem </moduleTempCode>
34
35     rule inferenceShell('topdeclslist('type(A:K,, B:K),, Rest:K)
36         ) =>
37         inferenceShell(Rest) //constructalpha
38     rule inferenceShell('topdeclslist('data(A:K,, B:K,, C:K,, D:
39         K),, Rest:K)) =>
40         inferenceShell(Rest)
41     rule inferenceShell('topdeclslist('newtype(A:K,, B:K,, C:K,,
42         D:K),, Rest:K)) =>
43         inferenceShell(Rest)
44     rule inferenceShell('topdeclslist('class(A:K,, B:K,, C:K,, D
45         :K),, Rest:K)) =>
46         inferenceShell(Rest)
47     rule inferenceShell('topdeclslist('instance(A:K,, B:K,, C:K
48         ,, D:K),, Rest:K)) =>
49         inferenceShell(Rest)
50     rule inferenceShell('topdeclslist('default(A:K,, B:K,, C:K,,
51         D:K),, Rest:K)) =>
52         inferenceShell(Rest)
53     rule inferenceShell('topdeclslist('foreign(A:K,, B:K,, C:K,,
54         D:K),, Rest:K)) =>
55         inferenceShell(Rest)
56     rule inferenceShell('topdeclslist('topdecldecl(A:K),, Rest:K
57         )) =>
58         typeInferenceFun(.ElemList, .Map,A,guessType(0)) ~>
59         inferenceShell(Rest)
60
61     rule <k> typeInferenceFun(.ElemList, Gamma:Map, '
62         declFunLhsRhs(Fn:K,, Lhsrhs:K), Guess:K) =>
63         typeInferenceFun(.ElemList, Gamma, Lhsrhs, Guess) ...</
64         k>
65     rule <k> typeInferenceFun(.ElemList, Gamma:Map, '
66         eqExpOptDecls(Ex:K,, Optdecls:K), Guess:K) =>
67         typeInferenceFun(.ElemList, Gamma, Ex, Guess) ...</k>
68

```

```

59 //T-App
60 //rule typeInferenceFun('aexpQVar(Var:K), Alpha:Map, Beta:
    Map, Delta:Map, (Var |-> Sigma:K) Gamma:Map,.K,.K) =>
    Sigma
61 //Gamma Proves x:phi(tau) if Gamma(x) = \forall alpha_1,
    ..., alpha_n . tau
62 //where phi replaces all occurrences of alpha_1, ...,
    alpha_n by monotypes tau_1, ..., tau_n
63
64 rule <k> typeInferenceFun(.ElemList, (Var |-> Type:K) Gamma:
    Map, 'aexpQVar(Var:K), Guess:KItem)
65     => mapBagResult(unifun(ListItem(unipair(Guess,
        freshInstance(Type, TypeIt)))) ...</k> //Variable
        rule
66     <typeIterator> TypeIt:Int => TypeIt +Int paramSize(Type
        ) </typeIterator>
67
68 //rule typeInferenceFun('aexpGCon(Gcon:K), Alpha:Map, (Gcon
    |-> Sigma:K) Beta:Map, Delta:Map, Gamma:Map,.K,.K) =>
    Sigma //T-App
69 //rule typeInferenceFun('aexpGCon(Gcon:K), Alpha:Map, Lol:
    Map, Delta:Map, Gamma:Map,.K,.K) => Sigma //T-App
70 //     <tempBeta> (Gcon |-> Sigma:K) Beta:Map </tempBeta>
71
72 rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'aexpGCon('
    conTyCon(Mid:K,, Gcon:K)), Guess:KItem)
73     => mapBagResult(unifun(ListItem(unipair(Guess,
        freshInstance(Type, TypeIt)))) ...</k> //Constant
        rule
74     <tempBeta> (ModPlusType(Mid,Gcon) |-> Type:K) Beta:Map
        </tempBeta>
75     <typeIterator> TypeIt:Int => TypeIt +Int paramSize(Type
        ) </typeIterator>
76
77 //lambda rule
78 //     rule <k> typeInferenceFun(Gamma:Map, 'lambdaFun(Apatlist:K
    ,, Ex:K), Guess:KItem)
79 //         => typeInferenceFun(genGamma(Apatlist,Gamma,
    guessType(TypeIt)), genLambda(Apatlist,Ex), guessType(TypeIt
    +Int 1))
80 //         ~> lambdaReturn(Guess,guessType(TypeIt),guessType(
    TypeIt +Int 1)) ...</k>

```



```
81 //      <typeIterator> TypeIt:Int => TypeIt +Int 2 </
      typeIterator>
82
83 //      rule <k> Sigma:Map ~> lambdaReturn(Tau:K, Tauone:K, Tautwo
      :K)
84 //      => compose(uniFun(ListItem(uniPair(typeSub(Sigma,Tau
      ),typeSub(Sigma,funtype(Tauone,Tautwo))))),Sigma) ...</k>
85
86 syntax KItem ::= typeInferenceFun(ElemList, Map, K, K) [
      strict(1)]
87 syntax KItem ::= typeInferenceFunLambda(ElemList, K, K, K) [
      strict(1)]
88 /* automatically generated by the strict(1) in typeInferenceFun
      or typeInferenceFunAux
89 rule typeInferenceFunAux(Es:ElemList, C:K, A:K, B:K) => Es ~>
      typeInferenceFun(HOLE, C, A, B)
90     requires notBool isKResult(Es)
91 rule Es:KResult ~> typeInferenceFunAux(HOLE, C:K,A:K, B:K) =>
      typeInferenceFun(Es, C, A, B)
92 */
93
94 //lambda rule
95 rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'lambdaFun(
      Apatlist:K,, Ex:K), Guess:KItem)
96     => typeInferenceFunLambda(val(typeInferenceFun(.
      ElemList, genGamma(Apatlist,Gamma,guessType(TypeIt)
      ), genLambda(Apatlist,Ex), guessType(TypeIt +Int 1)
      )), .ElemList, Guess, guessType(TypeIt),guessType(
      TypeIt +Int 1)) ...</k>
97     <typeIterator> TypeIt:Int => TypeIt +Int 2 </
      typeIterator>
98
99 rule <k> typeInferenceFunLambda(valValue(mapBagResult(Sigma:
      Map)), .ElemList, Tau:K, Tauone:K, Tautwo:K)
100     => mapBagResult(compose(uniFun(ListItem(uniPair(typeSub
      (Sigma,Tau),typeSub(Sigma,funtype(Tauone,Tautwo))))
      ,Sigma)) ...</k>
101
102 //rule <k> substi(S:Map) ~> lambdaReturn(Tau:K, Tauone:K,
      Tautwo:K)
103 //     => S[Tauone] ...</k>
104
105
```

```
106 //syntax KItem ::= appliReturn(Map, K, K, Map)
107 //syntax KItem ::= typeChildSub(Map, K) [function]
108
109 syntax KItem ::= typeInferenceFunAppli(ElemList, Map, K, K,
    Map) [strict(1)]
110
111 //application rule
112 rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'funApp(Eone
    :K,, Etwo:K), Guess:KItem)
113     => typeInferenceFunAppli(val(typeInferenceFun(.
        ElemList, Gamma, Eone, funtype(guessType(TypeIt),
        Guess))), .ElemList, Gamma, Etwo, guessType(TypeIt)
        , .Map) ...</k>
114     <typeIterator> TypeIt:Int => TypeIt +Int 1 </
        typeIterator>
115
116 rule <k> typeInferenceFunAppli(valValue(mapBagResult(
    Sigmaone:Map)), .ElemList, Gamma:Map, Etwo:KItem,
    guessType(TypeIt:Int), .Map)
117     => typeInferenceFunAppli(val(typeInferenceFun(.
        ElemList, gammaSub(Sigmaone, Gamma, .Map), Etwo,
        typeSub(Sigmaone, guessType(TypeIt))), .ElemList,
        .Map, .K, .K, Sigmaone) ...</k>
118
119 rule <k> typeInferenceFunAppli(valValue(mapBagResult(
    Sigmatwo:Map)), .ElemList, .Map, .K, .K, Sigmaone:Map)
120     => mapBagResult(compose(Sigmatwo, Sigmaone)) ...</k>
121
122 // rule <k> Sigmaone:Map ~> appliReturn(Gamma:Map, Etwo:KItem
    , guessType(TypeIt:Int), .Map)
123 //     => typeInferenceFun(gammaSub(Sigmaone, Gamma, .Map),
    Etwo, typeSub(Sigmaone, guessType(TypeIt)))
124 //     ~> appliReturn(.Map, .K, .K, Sigmaone) ...</k>
125
126 // rule <k> Sigmatwo:Map ~> appliReturn(.Map, .K, .K,
    Sigmaone:Map)
127 //     => compose(Sigmatwo, Sigmaone) ...</k>
128
129 syntax KItem ::= typeInferenceFunIfThen(ElemList, Map, K, K,
    K, Map, Map) [strict(1)]
130
131 //if_then_else rule
```

```
132     rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'ifThenElse(
        Eone:K,, Optsem:K,, Etwo:K,, Optsemtwo:K,, Ethree:K),
        Guess:KItem)
133     => typeInferenceFunIfThen(val(typeInferenceFun(.
        ElemList, Gamma, Eone, Bool)), .ElemList, Gamma,
        Etwo, Ethree, Guess, .Map, .Map) ...</k>
134
135     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
        Sigmaone:Map)), .ElemList, Gamma:Map, Etwo:KItem, Ethree:
        KItem, Guess:KItem, .Map, .Map)
136     => typeInferenceFunIfThen(val(typeInferenceFun(.
        ElemList, gammaSub(Sigmaone, Gamma, .Map), Etwo,
        typeSub(Sigmaone, Guess))), .ElemList, Gamma, .K,
        Ethree, Guess, Sigmaone, .Map) ...</k>
137
138     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
        Sigmatwo:Map)), .ElemList, Gamma:Map, .K, Ethree:KItem,
        Guess:KItem, Sigmaone:Map, .Map)
139     => typeInferenceFunIfThen(val(typeInferenceFun(.
        ElemList, gammaSub(compose(Sigmatwo, Sigmaone),
        Gamma, .Map), Ethree, typeSub(compose(Sigmatwo,
        Sigmaone), Guess))), .ElemList, .Map, .K, .K, .K,
        Sigmaone, Sigmatwo) ...</k>
140
141     rule <k> typeInferenceFunIfThen(valValue(mapBagResult(
        Sigmathree:Map)), .ElemList, .Map, .K, .K, .K, Sigmaone:
        Map, Sigmatwo:Map)
142     => mapBagResult(compose(compose(Sigmathree, Sigmatwo),
        Sigmaone)) ...</k>
143
144     syntax KItem ::= typeInferenceFunLetIn(ElemList, Map, Map, K
        , K, K, Int, Int, Map, Map) [strict(1)]
145     syntax KItem ::= grabLetDeclName(K, Int) [function]
146     syntax KItem ::= grabLetDeclExp(K, Int) [function]
147     syntax KItem ::= mapLookup(Map, K) [function]
148     syntax Map ::= makeDeclMap(K, Int, Map) [function]
149     syntax Map ::= applyGEN(Map, Map, Map, Map) [function]
150
151     //Haskell let in rule (let rec in exp + let in rule combined
        )
152     //gamma |- let rec f1 = e1 and f2 = e2 and f3 = e3 .... in e
        =>
```

```

153 //beta, [f1 -> tau1, f2 -> tau2, f3 -> tau3,...] + gamma |-
      e1 : tau1 | sigma1, [f1 -> sigma1(tau1), f2 -> sigma1(
      tau2), f3 -> sigma1(tau3),....] + sigma1(gamma) |- e2 :
      sigma1(tau2) | sigma2 [f1 -> sigma2 o sigma1(tau1), f2
      -> sigma2 o sigma1(tau2), f3 -> sigma2 o sigma1(tau3)
      ,....] + sigma2 o sigma1(gamma) |- e3 : sigma2 o sigma1(
      tau3) ..... [f1 -> gen(sigma_n o sigma2 o sigma1(tau1),
      sigma_n o sigma2 o sigma1(Gamma)), f2 -> gen(tau2), f3 ->
      gen(tau3),....] + gamma |- e : something
154 rule <k> typeInferenceFun(.ElemList, Gamma:Map, 'letIn(D:K,,
      E:K), Guess:KItem)
155     => typeInferenceFunLetIn(.ElemList, Gamma, makeDeclMap
      (D, TypeIt, .Map), D, E, Guess, 0, TypeIt, .Map,
      Beta) ...</k>
156     <typeIterator> TypeIt:Int => TypeIt +Int size(
      makeDeclMap(D, TypeIt, .Map)) </typeIterator>
157     <tempBeta> Beta:Map </tempBeta>
158
159 rule <k> typeInferenceFunLetIn(.ElemList, Gamma:Map, DeclMap
      :Map, D:KItem, E:KItem, Guess:KItem, Iter:Int, TypeIt:Int
      , OldSigma:Map, Beta:Map)
160     => typeInferenceFunLetIn(val(typeInferenceFun(.
      ElemList, Gamma DeclMap, grabLetDeclExp(D, Iter),
      mapLookup(DeclMap, grabLetDeclName(D, Iter))), .
      ElemList, Gamma, DeclMap, D, E, Guess, Iter,
      TypeIt, OldSigma, Beta) ...</k>
161     //=> typeInferenceFunLetIn(val(typeInferenceFun(
      DeclMap, grabLetDeclExp(D, Iter +Int TypeIt), Guess
      )), .ElemList, Gamma, DeclMap, D, E, Guess, Iter,
      TypeIt, OldSigma) ...</k>
162     requires Iter <Int (size(DeclMap))
163
164 rule <k> typeInferenceFunLetIn(valValue(mapBagResult(Sigma:
      Map)), .ElemList, Gamma:Map, DeclMap:Map, D:KItem, E:
      KItem, Guess:KItem, Iter:Int, TypeIt:Int, OldSigma:Map,
      Beta:Map)
165     => typeInferenceFunLetIn(.ElemList, gammaSub(Sigma,
      Gamma,.Map), gammaSub(Sigma, DeclMap,.Map), D, E,
      typeSub(Sigma, Guess), Iter +Int 1, TypeIt, compose
      (Sigma,OldSigma), Beta) ...</k>
166     requires Iter <Int (size(DeclMap))
167

```

```
168     rule <k> typeInferenceFunLetIn(.ElemList, Gamma:Map, DeclMap
      :Map, D:KItem, E:KItem, Guess:KItem, Iter:Int, TypeIt:Int
      , OldSigma:Map, Beta:Map)
169       => typeInferenceFunLetIn(val (typeInferenceFun(.
          ElemList, Gamma applyGEN(Gamma, DeclMap, .Map, Beta
          ), E, Guess)), .ElemList, Gamma, DeclMap, D, E,
          Guess, Iter, TypeIt, OldSigma, Beta) ...</k>
170       requires Iter >=Int (size(DeclMap))
171
172     rule <k> typeInferenceFunLetIn(valValue(mapBagResult(Sigma:
      Map)), .ElemList, Gamma:Map, DeclMap:Map, D:KItem, E:
      KItem, Guess:KItem, Iter:Int, TypeIt:Int, OldSigma:Map,
      Beta:Map)
173       => mapBagResult(compose(Sigma, OldSigma))...</k>
174       requires Iter >=Int (size(DeclMap))
175
176     rule mapLookup((Name |-> Type:KItem) DeclMap:Map, Name:KItem
      ) => Type
177     rule mapLookup(DeclMap:Map, Name:KItem) => Name
178       requires notBool(Name in keys(DeclMap))
179
180     //rule makeDeclMap('decls(A:K), TypeIt:Int, NewMap:Map) =>
      makeDeclMap(A, TypeIt +Int 1, NewMap)
181     rule makeDeclMap('decls(Dec:K), TypeIt:Int, NewMap:Map) =>
      makeDeclMap(Dec, TypeIt, NewMap)
182     rule makeDeclMap('declsList('declPatRhs('apatVar(Var:K),,
      Righthand:K),, Rest:K), TypeIt:Int, NewMap:Map) =>
      makeDeclMap('decls(Rest), TypeIt +Int 1, NewMap[Var <-
      guessType(TypeIt)])
183     rule makeDeclMap(.DeclList, TypeIt:Int, NewMap:Map) =>
      NewMap
184
185     rule grabLetDeclName('decls(Dec:K), Iter:Int) =>
      grabLetDeclName(Dec, Iter)
186     rule grabLetDeclName('declsList(Dec:K,, Rest:K), Iter:Int)
      => grabLetDeclName(Rest, Iter -Int 1)
187       requires Iter >Int 0
188     rule grabLetDeclName('declsList('declPatRhs('apatVar(Var:K)
      ,, Righthand:K),, Rest:K), Iter:Int) => Var
189       requires Iter <=Int 0
190
191
```

```
192     rule grabLetDeclExp('decls(Dec:K), Iter:Int) =>
      grabLetDeclExp(Dec, Iter)
193     rule grabLetDeclExp('declsList(Dec:K,, Rest:K), Iter:Int) =>
      grabLetDeclExp(Rest, Iter -Int 1)
194     requires Iter >Int 0
195     rule grabLetDeclExp('declsList('declPatRhs('apatVar(Var:K),,
      Righthand:K),, Rest:K), Iter:Int) => grabLetDeclExp(
      Righthand, Iter)
196     requires Iter <=Int 0
197     rule grabLetDeclExp('eqExpOptDecls(Righthand:K,, Opt:K),
      Iter:Int) => 'eqExpOptDecls(Righthand,, Opt)
198
199     rule genGamma('apatVar(Vari:K), Gamma:Map, Guess:K) => Gamma
      [Vari <- Guess]
200     rule genGamma('apatCon(Vari:K,, Pattwo:K), Gamma:Map, Guess:
      K) => Gamma[Vari <- Guess]
201
202     rule genLambda('apatVar(Vari:K), Ex:K) => Ex
203     rule genLambda('apatCon(Vari:K,, Pattwo:K), Ex:K) => '
      lambdaFun(Pattwo,, Ex)
204
205
206     rule gammaSub(Sigma:Map, (Key:KItem |-> Type:KItem) Gamma:
      Map, Newgamma:Map)
207     => gammaSub(Sigma, Gamma, Newgamma[Key <- typeSub(Sigma,
      Type) ] )
208     // => gammaSub(Sigma, Gamma, Newgamma[Key <- typeChildSub(
      Sigma, Type) ] )
209
210     rule gammaSub(Sigma:Map, .Map, Newgamma:Map)
211     => Newgamma
212
213     //rule typeChildSub((guessType(TypeIt) |-> Type:KItem) Sigma
      :Map, guessType(TypeIt:Int)) => Type
214
215     //rule typeChildSub(Sigma:Map, guessType(TypeIt:Int)) =>
      guessType(TypeIt)
216     //      requires notBool (guessType(TypeIt) in keys(Sigma))
217
218     rule freshInstance(guessType(TypeIt:Int), Iter:Int) =>
      guessType(TypeIt)
219     rule freshInstance(forAll(.Set, B:K), Iter:Int) => B
```

```
220     rule freshInstance(forAll(SetItem(C:KItem) A:Set, B:K), Iter
      :Int) => freshInstance(forAll(A, freshInstanceInner(C, B,
        Iter)), Iter +Int 1)
221
222     syntax KItem ::= freshInstanceInner(K,K,Int) [function]
223
224     rule freshInstanceInner(Repl:KItem, funtype(A:K, B:K), Iter:
      Int) => funtype(freshInstanceInner(Repl,A,Iter),
        freshInstanceInner(Repl,B,Iter))
225     rule freshInstanceInner(Repl:KItem, Repl, Iter:Int) =>
      guessType(Iter)
226     rule freshInstanceInner(Repl:KItem, Target:KItem, Iter:Int)
      => Target [owise]
227
228     rule paramSize(forAll(A:Set, B:K)) => size(A)
229     rule paramSize(A:K) => 0 [owise]
230
231
232     rule applyGEN(Gamma:Map, (Key:KItem |-> Type:KItem) DeclMap
      :Map, NewMap:Map, Beta:Map)
233     => applyGEN(Gamma, DeclMap, NewMap[Key <- gen(Gamma, Type
      , Beta)], Beta)
234
235     rule applyGEN(Gamma:Map, .Map, NewMap:Map, Beta:Map)
236     => NewMap
237
238     //GEN
239     //GEN(Gamma, Tau) => Forall alpha
240
241     syntax KItem ::= gen(Map, K, Map) [function]
242     syntax Set ::= freeVarsTy(K, Map) [function]
243     syntax Set ::= freeVarsEnv(Map, Map) [function]
244     //syntax KItem ::= setBag(Set)
245     // syntax Set ::= listToSet(List, Set) [function]
246
247
248     rule gen(Gamma:Map, forAll(Para:Set, Tau:KItem), Beta:Map)
      => forAll(freeVarsTy(forAll(Para:Set, Tau), Beta) -Set
        freeVarsEnv(Gamma, Beta), Tau)
249     rule gen(Gamma:Map, Tau:KItem, Beta:Map) => forAll(
      freeVarsTy(Tau, Beta) -Set freeVarsEnv(Gamma, Beta), Tau)
      [owise]
250
```

```
251 //rule gen(Gamma:Map, forAll(Para:Set, Tau:KItem), Beta:Map)
    => forAll(freeVarsTy(forAll(Para:Set, Tau), Beta) -Set
    freeVarsEnv(Gamma, Beta), Tau)
252
253 rule freeVarsTy(guessType(TypeIt:Int), Beta:Map) => SetItem(
    guessType(TypeIt:Int))
254 rule freeVarsTy(funtype(Tauone:KItem, Tautwo:KItem), Beta:
    Map) => freeVarsTy(Tauone, Beta) freeVarsTy(Tautwo, Beta)
255 rule freeVarsTy(Tau:KItem, Beta:Map) => .Set
256     requires (forAll(.Set, Tau)) in values(Beta)
257 rule freeVarsTy(forAll(Para:Set, Tau:KItem), Beta:Map) =>
    freeVarsTy(Tau, Beta) -Set Para
258 rule freeVarsEnv(Gamma:Map, Beta:Map) => listToSet(values(
    Beta), .Set)
259
260
261 // rule listToSet(ListItem(A:KItem) L:List, S:Set) =>
    listToSet(L, SetItem(A) S)
262 // rule listToSet(.List, S:Set) => S
263
264 ///////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
265
266 //Unification
267
268 syntax Map ::= uniFun(List) [function]
269 //syntax List ::= uniSub(K,K,K) [function]
270 syntax Bool ::= isVarType(K) [function]
271 syntax Bool ::= notChildVar(K,K) [function]
272 syntax KItem ::= uniPair(K,K)
273
274 syntax List ::= uniSub(Map,K) [function] //apply
    substitution to unification
275
276 syntax KItem ::= typeSub(Map,K) [function] //apply
    substitution to type
277 syntax Map ::= compose(Map,Map) [function]
278
279 // syntax KItem ::= Map
280
281 rule uniFun(.List) => .Map //substi(.K,.K) is id
    substitution
282
```



```

283     rule uniFun(ListItem(uniPair(S:K,S)) Rest:List) => uniFun(
        Rest) //delete rule
284
285     // rule uniFun(SetItem(I:K)) => .K //uniFun(Rest) //delete
        rule
286
287     rule uniFun(ListItem(uniPair(S:K,T:K)) Rest:List) => uniFun(
        ListItem(uniPair(T,S)) Rest) //orient rule
288         requires isVarType(T) andBool (notBool isVarType(S))
289
290     //rule uniFun(ListItem(uniPair(forAll(Svars:List,S:K),forAll
        (.List,T:K))) Rest:List,Sigma:Map) => uniFun(ListItem(
        uniPair(forAll(.List,T),forAll(Svars,S))) Rest,Sigma) //
        orient rule
291     //   requires Svars !=K .List
292
293     //rule uniFun(ListItem(uniPair(guessType(S:Int),forAll(.List
        ,T:K))) Rest:List,Sigma:Map) => uniFun(ListItem(uniPair(
        forAll(.List,T:K),guessType(S))) Rest,Sigma) //orient
        rule
294
295     // rule uniFun(ListItem(uniPair(forAll(.List,S:K),T:K)) Rest:
        List, Sigma:Map) => uniFun(uniSub('aexpQVar(Var),T,Rest),
        Sigma['aexpQVar(Var) <- T]) //eliminate rule
296     //   requires notChildVar('aexpQVar(Var:K),T)
297
298     rule uniFun(ListItem(uniPair(funtype(A:K, B:K), funtype(C:K,
        D:K))) Rest:List) => uniFun(ListItem(uniPair(A, C))
        ListItem(uniPair(B, D)) Rest:List) //decompose rule
        function type
299
300     rule uniFun(ListItem(uniPair(S:K,T:K)) Rest:List)
301         => compose((S |-> typeSub(uniFun(uniSub((S |-> T),Rest)),T
        )),uniFun(uniSub((S |-> T),Rest))) //eliminate rule
302     // => compose(uniFun(uniSub((S |-> T),Rest)),(S |-> typeSub
        (uniFun(uniSub((S |-> T),Rest)),T))) //eliminate rule
303         requires isVarType(S) andBool notChildVar(S,T)
304
305     rule isVarType(S:K) => true
306         requires getKLabel(S) ==KLabel 'guessType
307     rule isVarType(S:K) => false [otherwise]
308
309     rule notChildVar(S:K,T:K) => true

```

```
310
311     rule uniSub(Sigma:Map, .List) => .List
312     rule uniSub(.Map, L:List) => L
313     rule uniSub(Sigma:Map, Rest:List ListItem(uniPair(A:K, B:K))
314         ) => uniSub(Sigma, Rest) ListItem(uniPair(typeSub(Sigma,
315             A), typeSub(Sigma, B)))
316
317     //rule typeSub(substi(.Map), Tau:KItem) => Tau
318     rule typeSub(Sigma:Map (Tau |-> Newtau:KItem), Tau:KItem) =>
319         typeSub(Sigma (Tau |-> Newtau), Newtau)
320     rule typeSub(Sigma:Map, funtype(Tauone:KItem, Tautwo:KItem))
321         => funtype(typeSub(Sigma, Tauone), typeSub(Sigma, Tautwo))
322     rule typeSub(Sigma:Map, Tau:KItem) => Tau [owise]
323
324     syntax Map ::= composeIn(Map, Map, Map, K, K) [function]
325
326     rule compose(Sigmaone:Map, Sigmatwo:Map) => composeIn(
327         Sigmaone, Sigmatwo, .Map, .K, .K)
328
329     rule composeIn(Sigmaone:Map, (Key:KItem |-> Type:KItem)
330         Sigmatwo:Map, NewMap:Map, .K, .K) => composeIn(Sigmaone,
331         Sigmatwo, NewMap, Key, Type)
332
333     rule composeIn((Keyone |-> Typetwo:KItem) Sigmaone:Map,
334         Sigmatwo:Map, NewMap:Map, Keyone:KItem, Typeone:KItem) =>
335         composeIn(Sigmaone, Sigmatwo, NewMap, Keyone, Typeone)
336
337     rule composeIn((Typeone |-> Typetwo:KItem) Sigmaone:Map,
338         Sigmatwo:Map, NewMap:Map, Keyone:KItem, Typeone:KItem) =>
339         composeIn((Typeone |-> Typetwo) Sigmaone, Sigmatwo,
340         NewMap[Keyone <- Typetwo], .K, .K)
341         requires notBool(Keyone in keys(Sigmaone))
342
343     rule composeIn(Sigmaone:Map, Sigmatwo:Map, NewMap:Map,
344         Keyone:KItem, Typeone:KItem) => composeIn(Sigmaone,
345         Sigmatwo, NewMap[Keyone <- Typeone], .K, .K) [owise]
346
347     rule composeIn(Sigmaone:Map, .Map, NewMap:Map, .K, .K) =>
348         Sigmaone NewMap
349
350     //rule composeIn(Sigmaone:Map, .Map, .Map, .K, .K) =>
351         Sigmaone
```

```
337 //rule composeIn((Key:KItem |-> Type:KItem) Sigmaone:Map, .
    Map, NewMap:Map) => composeIn(Sigmaone, .Map, NewMap[Key
    <- mapLookup(Sigmaone, Type)])
338
339 //rule compose(Sigmaone:Map, Sigmatwo:Map) => updateMap(
    Sigmaone, Sigmatwo)
340 //rule compose(Sigmaone:Map, (Keytwo:KItem |-> Valtwo:KItem)
    Sigmatwo:Map) => compose(Sigmaone[Keytwo <- Valtwo][
    Valtwo <- mapLookup(Sigmaone, Keytwo)], Sigmatwo)
341 //rule compose(Sigmaone:Map, (Key:KItem |-> Type:KItem)
    Sigmatwo:Map, .K) => compose(Sigmaone[Type <- mapLookup(
    Sigmaone, Key)][Key <- Type], Sigmatwo, mapLookup(
    Sigmaone, Key))
342 //rule compose(Sigmaone:Map, (Key:KItem |-> Type:KItem)
    Sigmatwo:Map) => composeIn(Sigmaone, Sigmatwo, mapLookup(
    Sigmaone, Key))
343 //      requires (notBool (Type in values(Sigmaone))) andBool
    (Type /=K mapLookup(Sigmaone, Key))
344 //rule compose(Sigmaone:Map, (Key:KItem |-> Type:KItem)
    Sigmatwo:Map) => compose(Sigmaone[Key <- Type][Type <-
    mapLookup(Sigmaone, Key)], Sigmatwo)
345 //      requires (notBool (Type in values(Sigmaone))) andBool
    (Type /=K mapLookup(Sigmaone, Key))
346 // rule compose(Sigmaone:Map, (Keytwo:KItem |-> Valtwo:KItem)
    Sigmatwo:Map) => compose(Sigmaone[Valtwo <- mapLookup(
    Sigmaone, Keytwo)], Sigmatwo)
347 //      requires (Valtwo in values(Sigmaone)) andBool (Valtwo
    /=K mapLookup(Sigmaone, Keytwo))
348 //rule compose(Sigmaone:Map, (Keytwo:KItem |-> Valtwo:KItem)
    Sigmatwo:Map) => compose((Keytwo |-> Valtwo) Sigmaone,
    Sigmatwo)
349 // requires notBool (Keytwo in keys(Sigmaone))
350 //rule compose(Sigmaone:Map, .Map) => Sigmaone
351 // rule compose(substi(Sone:K, Tone:K), substi(Stwo:K, Ttwo:K))
    => substi(typeSub(substi(Stwo, Ttwo), Sone), Tone)
352
353
354 // rule notChildVar('aexpQVar(Var:K), T)
355
356
357 //T-Var
358 // rule typeInferenceFun('funApp(Eone:K,, Etwo:K), Alpha:Map,
    Beta:Map, Delta:Map, Gamma:Map, .K, .K) =>
```

```
359 //      typeInferenceFun('funApp(Eone,, Etwo), Alpha, Beta,
      Delta, Gamma,typeInferenceFun(Eone,Alpha, Beta, Delta, Gamma
      ,.K,.K),typeInferenceFun(Etwo,Alpha, Beta, Delta, Gamma,.K,.K
      ))
360 //      rule typeInferenceFun('funApp(Eone:K,, Etwo:K), Alpha:Map,
      Beta:Map, Delta:Map, Gamma:Map, funtype(Tauone:K, Tautwo:K),
      Tauone) => Tautwo
361
362      //T-Lam
363 //      rule typeInferenceFun('lambdaFun(Apatlist:K,, Ex:K), Alpha
      :Map, Beta:Map, Delta:Map, Gamma:Map,.K,.K) =>
364 //      typeInferenceFun('lambdaFun(Apatlist,, Ex), Alpha,
      Beta, Delta, Gamma,typeInferenceFun(Ex, Alpha, Beta, Delta,
      genGamma(Apatlist,Gamma),.K,.K),.K)
365
366 //      rule typeInferenceFun('lambdaFun(Apatlist:K,, Ex:K), Alpha
      :Map, Beta:Map, Delta:Map, Gamma:Map,Tautwo:K,.K) => Tautwo
367
368 endmodule
```

REFERENCES