

```
<?xml version="1.0"?>
```

```
<!-- FILE : faber_model_2000.xml
```

```
CREATED : 19th Septemeber 2003
```

```
LAST MODIFIED : 19th Septemeber 2003
```

```
AUTHOR : Catherine Lloyd  
The Bioengineering Institute  
The University of Auckland
```

```
MODEL STATUS : This model conforms to the CellML 1.1 Specification and the CellML Metadata 1.0
```

```
DESCRIPTION : This file contains a CellML description of Faber and Rudy's 2000 mathematical model
```

```
CHANGES:
```

```
-->
```

```
<model
```

```
  name="faber_model_2000"
```

```
  cmeta:id="faber_model_2000"
```

```
  xmlns="http://www.cellml.org/cellml/1.1#"
```

```
  xmlns:cellml="http://www.cellml.org/cellml/1.1#"
```

```
  xmlns:cmeta="http://www.cellml.org/metadata/1.0#"
```

```
  xmlns:xlink="http://www.w3.org/1999/xlink">
```

```
<rdf:RDF
```

```
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
```

```
  xmlns:cmeta="http://www.cellml.org/metadata/1.0#"
```

```
  xmlns:bqs="http://www.cellml.org/bqs/1.1#"
```

```
  xmlns:dc="http://purl.org/dc/elements/1.1/"
```

```
  xmlns:dcterms="http://purl.org/dc/terms/"
```

```
  xmlns:vCard="http://www.w3.org/2001/vcard-rdf/3.0#">
```

```
<!--
```

```
  The following RDF block contains metadata that applies to this document  
  as a whole, as indicated by the empty about attribute on the  
  <rdf:Description> element.
```

```
-->
```

```
<rdf:Description rdf:about="">
```

```
<!--
```

```
  The Model Builder Metadata. The Dublin Core "creator" element is used  
  to indicate the person who translated the model into CellML.
```

```
-->
```

```
<dc:creator rdf:parseType="Resource">
```

```
<vCard:N rdf:parseType="Resource">
```

```
<vCard:Family>Lloyd</vCard:Family>
```

```
<vCard:Given>Catherine</vCard:Given>
```

```
<vCard:Other>May</vCard:Other>
```

```
</vCard:N>
```

```
<vCard:EMAIL rdf:parseType="Resource">
```

```
<rdf:value>c.lloyd@auckland.ac.nz</rdf:value>
```

```
<rdf:type rdf:resource="http://imc.org/vCard/3.0#internet" />
```

```
</vCard:EMAIL>
```

```
<vCard:ORG rdf:parseType="Resource">
```

```
<vCard:Orgname>The University of Auckland</vCard:Orgname>
```

```
<vCard:Orgunit>The Bioengineering Institute</vCard:Orgunit>
```

```
</vCard:ORG>
```

```
</dc:creator>
```

```

<!--
  The Creation Date metadata. This is the date on which the model
  was translated into CellML.
-->
<dcterms:created rdf:parseType="Resource">
  <dcterms:W3CDTF>2003-09-19</dcterms:W3CDTF>
</dcterms:created>

<!--
  The Modification History metadata. This lists the changes that have been
  made to the document, who made the changes, and when they were made.
-->

<!-- The Publisher metadata. -->
<dc:publisher>
  The University of Auckland, The Bioengineering Institute
</dc:publisher>
</rdf:Description>

<!--
  The following metadata refers to the model itself, as indicated by the
  reference to the ID "faber_model_2000", which is declared on the
  <model> element.
-->
<rdf:Description rdf:about="#faber_model_2000">
  <!-- A human readable name for the model. -->
  <dc:title>
    The Faber-Rudy 2000 Model of Mammalian Ventricular Cardiac Action
    Potentials in Calcium Overloaded Myocytes.
  </dc:title>

  <!-- A comment regarding the model. -->
  <cmeta:comment rdf:parseType="Resource">
    <rdf:value>
      This is the CellML description of Faber and Rudy's mathematical model
      of the mammalian cardiac ventricular action potential in calcium
      overloaded myocytes. It is a development on the Luo-Rudy 1994 dynamic
    </rdf:value>
    <!-- The creator of the comment. -->
    <dc:creator rdf:parseType="Resource">
      <vCard:FN>Catherine Lloyd</vCard:FN>
    </dc:creator>
  </cmeta:comment>

  <!-- The model is relevant to all mammals. -->
  <cmeta:species>Mammalia</cmeta:species>

  <cmeta:bio_entity>Ventricular Myocyte</cmeta:bio_entity>

<!--
  The CellML Metadata Specification recommends that bibliographic metadata
  is used to provide information about the original model reference. The
  "identifier" attribute on the "BibliographicReference" class provides an
  elegant way to identify a cited reference using a database identifier
  date, etc can be looked up on the database.
-->
<bqs:reference rdf:parseType="Resource">
  <bqs:Pubmed_id>10777735</bqs:Pubmed_id>

```

```

<bqs:JournalArticle rdf:parseType="Resource">
  <dc:creator>
    <rdf:Seq>
      <rdf:li rdf:parseType="Resource">
        <bqs:Person rdf:parseType="Resource">
          <vCard:N rdf:parseType="Resource">
            <vCard:Family>Faber</vCard:Family>
            <vCard:Given>Gregory</vCard:Given>
            <vCard:Other>M</vCard:Other>
          </vCard:N>
        </bqs:Person>
      </rdf:li>
      <rdf:li rdf:parseType="Resource">
        <bqs:Person rdf:parseType="Resource">
          <vCard:N rdf:parseType="Resource">
            <vCard:Family>Rudy</vCard:Family>
            <vCard:Given>Yoram</vCard:Given>
          </vCard:N>
        </bqs:Person>
      </rdf:li>
    </rdf:Seq>
  </dc:creator>
  <dc:title>
    Action Potential and Contractility Changes in [Na+]i Overloaded
  </dc:title>
  <dcterms:issued rdf:parseType="Resource">
    <dcterms:W3CDTF>2000-05</dcterms:W3CDTF>
  </dcterms:issued>
  <bqs:Journal rdf:parseType="Resource">
    <dc:title>Biophysical Journal</dc:title>
  </bqs:Journal>
  <bqs:volume>78</bqs:volume>
  <bqs:first_page>2392</bqs:first_page>
  <bqs:last_page>2404</bqs:last_page>
</bqs:JournalArticle>
</bqs:reference>
</rdf:Description>
</rdf:RDF>

<import xlink:href="http://www.cellml.org/examples/models/LR_II_model_1994.xml">
  <units name="millisecond" units_ref="millisecond" />
  <units name="per_millisecond" units_ref="per_millisecond" />
  <units name="millivolt" units_ref="millivolt" />
  <units name="per_millivolt" units_ref="per_millivolt" />
  <units name="per_millivolt_millisecond" units_ref="per_millivolt_millisecond" />
  <units name="milliS_per_microF" units_ref="milliS_per_microF" />
  <units name="microF" units_ref="microF" />
  <units name="microA_per_microF" units_ref="microA_per_microF" />
  <units name="millimolar_per_millisecond" units_ref="millimolar_per_millisecond" />
  <units name="millimolar" units_ref="millimolar" />
  <units name="micromolar" units_ref="micromolar" />
  <units name="joule_per_kilomole_kelvin" units_ref="joule_per_kilomole_kelvin" />
  <units name="coulomb_per_mole" units_ref="coulomb_per_mole" />
  <units name="cm_per_second" units_ref="cm_per_second" />
  <units name="mm2" units_ref="mm2" />
  <units name="micro_litre" units_ref="micro_litre" />

  <component name="environment" component_ref="environment" />
  <component name="fast_sodium_current" component_ref="fast_sodium_current" />

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    <component name="time_independent_potassium_current" component_ref="time_independent_potassium_current" />
    <component name="plateau_potassium_current" component_ref="plateau_potassium_current" />
    <component name="sodium_background_current" component_ref="sodium_background_current" />
    <component name="sodium_potassium_pump" component_ref="sodium_potassium_pump" />
</import>

<import xlink:href="http://www.cellml.org/examples/models/zeng_model_1995.xml">
    <component name="L_type_Ca_channel" component_ref="L_type_Ca_channel" />
    <component name="T_type_Ca_channel" component_ref="T_type_Ca_channel" />
    <component name="rapid_time_dependent_potassium_current" component_ref="rapid_time_dependent_potassium_current" />
    <component name="sarcolemmal_calcium_pump" component_ref="sarcolemmal_calcium_pump" />
    <component name="calcium_background_current" component_ref="calcium_background_current" />
    <component name="non_specific_calcium_activated_current" component_ref="non_specific_calcium_activated_current" />
    <component name="Na_Ca_exchanger" component_ref="Na_Ca_exchanger" />
    <component name="calcium_buffers_in_the_myoplasm" component_ref="calcium_buffers_in_the_myoplasm" />
    <component name="calcium_fluxes_in_the_SR" component_ref="calcium_fluxes_in_the_SR" />
</import>

<import xlink:href="http://www.cellml.org/examples/models/shaw_model_1997.xml">
    <units name="cm2" units_ref="cm2" />

    <component name="ATP_dependent_potassium_current" component_ref="ATP_dependent_potassium_current" />
</import>

<import xlink:href="http://www.cellml.org/examples/models/viswanathan_model_1999.xml">
    <units name="nanoS_per_cm2" units_ref="nanoS_per_cm2" />

    <component name="slow_time_dependent_potassium_current" component_ref="slow_time_dependent_potassium_current" />
</import>

<component name="membrane">
    <variable name="V" public_interface="out" initial_value="-84.624" units="millivolt" />
    <variable name="R" public_interface="out" initial_value="8314.0" units="joule_per_kilomole" />
    <variable name="T" public_interface="out" initial_value="310.0" units="kelvin" />
    <variable name="F" public_interface="out" initial_value="96500.0" units="coulomb_per_mole" />

    <variable name="Cm" initial_value="1.0" units="microF" />
    <variable name="I_st" initial_value="-100.0" units="microA_per_microF" />

    <variable name="time" public_interface="in" units="millisecond" />
    <variable name="i_Na" public_interface="in" units="microA_per_microF" />
    <variable name="i_Ca_L" public_interface="in" units="microA_per_microF" />
    <variable name="i_Ca_T" public_interface="in" units="microA_per_microF" />
    <variable name="i_Kr" public_interface="in" units="microA_per_microF" />
    <variable name="i_Ks" public_interface="in" units="microA_per_microF" />
    <variable name="i_KNa" public_interface="in" units="microA_per_microF" />
    <variable name="i_NaCa" public_interface="in" units="microA_per_microF" />
    <variable name="i_K1" public_interface="in" units="microA_per_microF" />
    <variable name="i_Kp" public_interface="in" units="microA_per_microF" />
    <variable name="i_p_Ca" public_interface="in" units="microA_per_microF" />
    <variable name="i_Na_b" public_interface="in" units="microA_per_microF" />
    <variable name="i_Ca_b" public_interface="in" units="microA_per_microF" />
    <variable name="i_NaK" public_interface="in" units="microA_per_microF" />
    <variable name="i_ns_Ca" public_interface="in" units="microA_per_microF" />
    <variable name="i_K_ATP" public_interface="in" units="microA_per_microF" />

```

```

<math xmlns="http://www.w3.org/1998/Math/MathML">
  <apply id="membrane_voltage_diff_eq"><eq />
    <apply><diff />
      <bvar><ci> time </ci></bvar>
      <ci> V </ci>
    </apply>
    <apply><times />
      <apply><minus />
        <apply><divide />
          <cn cellml:units="dimensionless"> 1.0 </cn>
          <ci> Cm </ci>
        </apply>
      </apply>
      <apply><plus />
        <ci> i_Na </ci>
        <ci> i_Ca_L </ci>
        <ci> i_Ca_T </ci>
        <ci> i_Kr </ci>
        <ci> i_Ks </ci>
        <ci> i_Kl </ci>
        <ci> i_KNa </ci>
        <ci> i_Kp </ci>
        <ci> i_K_ATP </ci>
        <ci> i_NaCa </ci>
        <ci> i_p_Ca </ci>
        <ci> i_Na_b </ci>
        <ci> i_Ca_b </ci>
        <ci> i_NaK </ci>
        <ci> i_ns.Ca </ci>
        <ci> I_st </ci>
      </apply>
    </apply>
  </math>
</component>

<component name="sodium_activated_potassium_current">
  <variable name="i_KNa" public_interface="out" units="microA_per_microF" />

  <variable name="g_KNa" initial_value="0.12848" units="milliS_per_cm2" />
  <variable name="P_oV" units="dimensionless" />
  <variable name="P_oNai" units="dimensionless" />
  <variable name="E_K" units="millivolt" />
  <variable name="K_D" initial_value="66.0" units="millimolar" />
  <variable name="n" initial_value="2.8" units="dimensionless" />

  <variable name="time" public_interface="in" units="millisecond" />
  <variable name="V" public_interface="in" units="millivolt" />
  <variable name="Nai" public_interface="in" units="millimolar" />
  <variable name="Ki" public_interface="in" units="millimolar" />
  <variable name="Ko" public_interface="in" units="millimolar" />
  <variable name="R" public_interface="in" units="joule_per_kilomole_kelvin" />
  <variable name="T" public_interface="in" units="kelvin" />
  <variable name="F" public_interface="in" units="coulomb_per_mole" />

  <math xmlns="http://www.w3.org/1998/Math/MathML">
    <apply id="i_KNa_calculation"><eq />
      <ci> i_KNa </ci>

```

```

<apply><times />
  <ci> g_KNa </ci>
  <ci> P_oNai </ci>
  <ci> P_oV </ci>
  <apply><minus />
    <ci> V </ci>
    <ci> E_K </ci>
  </apply>
</apply>
</apply>

```

```

<apply id="E_K_calculation"><eq />
  <ci> E_K </ci>
  <apply><times />
    <apply><divide />
      <apply><times />
        <ci> R </ci>
        <ci> T </ci>
      </apply>
      <ci> F </ci>
    </apply>
    <apply><ln />
      <apply><divide />
        <ci> K_o </ci>
        <ci> K_i </ci>
      </apply>
    </apply>
  </apply>
</apply>

```

```

<apply id="P_oV_calculation"><eq />
  <ci> P_oV </ci>
  <apply><minus />
    <cn cellml:units="dimensionless"> 0.8 </cn>
    <apply><divide />
      <cn cellml:units="dimensionless"> 0.65 </cn>
      <apply><plus />
        <cn cellml:units="dimensionless"> 1.0 </cn>
        <apply><exp />
          <apply><divide />
            <apply><plus />
              <ci> V </ci>
              <cn cellml:units="millivolt"> 125.0 </cn>
            </apply>
            <cn cellml:units="millivolt"> 15.0 </cn>
          </apply>
        </apply>
      </apply>
    </apply>
  </apply>

```

```

<apply id="P_oNai_calculation"><eq />
  <ci> P_oNai </ci>
  <apply><divide />
    <cn cellml:units="dimensionless"> 0.85 </cn>
    <apply><plus />
      <cn cellml:units="dimensionless"> 1.0 </cn>
      <apply><power />

```

```

    <apply><divide />
      <ci> K_D </ci>
      <ci> Nai </ci>
    </apply>
    <ci> n </ci>
  </apply>
</apply>
</math>
</component>

```

```

<component name="ionic_concentrations">
  <variable name="Nai" public_interface="out" initial_value="10.0" units="millimolar" />
  <variable name="Nao" public_interface="out" initial_value="140.0" units="millimolar" />
  <variable name="Cai" public_interface="out" initial_value="0.12" units="micromolar" />
  <variable name="Cao" public_interface="out" initial_value="1.8" units="millimolar" />
  <variable name="Ki" public_interface="out" initial_value="145.0" units="millimolar" />
  <variable name="Ko" public_interface="out" initial_value="5.4" units="millimolar" />
  <variable name="Ca_JSR" public_interface="out" units="millimolar" />
  <variable name="Ca_NSR" public_interface="out" initial_value="15.0" units="millimolar" />
  <variable name="Ca_foot" units="micromolar" />

  <variable name="A_cap" initial_value="0.000153" units="mm2" />
  <variable name="R_A_V" units="dimensionless" />
  <variable name="V_myo" units="micro_litre" />
  <variable name="V_cleft" units="micro_litre" />
  <variable name="V_JSR" units="micro_litre" />
  <variable name="V_NSR" units="micro_litre" />

  <variable name="time" public_interface="in" units="millisecond" />
  <variable name="F" public_interface="in" units="coulomb_per_mole" />
  <variable name="i_Na" public_interface="in" units="microA_per_microF" />
  <variable name="i_Na_b" public_interface="in" units="microA_per_microF" />
  <variable name="i_ns_Na" public_interface="in" units="microA_per_microF" />
  <variable name="i_NaK" public_interface="in" units="microA_per_microF" />
  <variable name="i_CaCa" public_interface="in" units="microA_per_microF" />
  <variable name="i_Ca_T" public_interface="in" units="microA_per_microF" />
  <variable name="i_CaK" public_interface="in" units="microA_per_microF" />
  <variable name="i_p_Ca" public_interface="in" units="microA_per_microF" />
  <variable name="i_Ca_b" public_interface="in" units="microA_per_microF" />
  <variable name="i_Kr" public_interface="in" units="microA_per_microF" />
  <variable name="i_Ks" public_interface="in" units="microA_per_microF" />
  <variable name="i_Kl" public_interface="in" units="microA_per_microF" />
  <variable name="i_KNa" public_interface="in" units="microA_per_microF" />
  <variable name="i_Kp" public_interface="in" units="microA_per_microF" />
  <variable name="i_K_ATP" public_interface="in" units="microA_per_microF" />
  <variable name="i_tr" public_interface="in" units="millimolar_per_millisecond" />
  <variable name="i_rel" public_interface="in" units="millimolar_per_millisecond" />
  <variable name="i_leak" public_interface="in" units="millimolar_per_millisecond" />
  <variable name="i_up" public_interface="in" units="millimolar_per_millisecond" />

  <math xmlns="http://www.w3.org/1998/Math/MathML">
    <apply id="sodium_diff_eq"><eq />
      <apply><diff />
        <bvar><ci> time </ci></bvar>
        <ci> Nai </ci>
      </apply>
      <apply><times />

```

```

<apply><minus />
  <apply><plus />
    <ci> i_Na </ci>
    <ci> i_CaNa </ci>
    <ci> i_Na_b </ci>
    <ci> i_ns_Na </ci>
    <apply><times />
      <ci> i_NaCa </ci>
      <cn cellml:units="dimensionless"> 3.0 </cn>
    </apply>
    <apply><times />
      <ci> i_NaK </ci>
      <cn cellml:units="dimensionless"> 3.0 </cn>
    </apply>
  </apply>
</apply>
<apply><divide />
  <ci> A_cap </ci>
  <apply><times />
    <ci> V_myo </ci>
    <ci> F </ci>
  </apply>
</apply>
</apply>
</apply>
</apply>
<apply id="calcium_internal_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Cai </ci>
  </apply>
  <apply><plus />
    <apply><times />
      <apply><minus />
        <apply><plus />
          <ci> i_CaCa </ci>
          <ci> i_p_Ca </ci>
          <ci> i_Ca_b </ci>
          <ci> i_Ca_T </ci>
        </apply>
        <ci> i_NaCa </ci>
      </apply>
      <apply><divide />
        <ci> A_cap </ci>
        <apply><times />
          <cn cellml:units="dimensionless"> 2.0 </cn>
          <ci> V_myo </ci>
          <ci> F </ci>
        </apply>
      </apply>
    </apply>
    <apply><times />
      <ci> i_rel </ci>
      <apply><divide />
        <ci> V_JSR </ci>
        <ci> V_myo </ci>
      </apply>
    </apply>
  </apply>
  <apply><times />

```

```

    <apply><minus />
      <ci> i_leak </ci>
      <ci> i_up </ci>
    </apply>
    <apply><divide />
      <ci> V_NSR </ci>
      <ci> V_myo </ci>
    </apply>
  </apply>
</apply>
</apply>
</apply>
</apply>

<apply id="potassium_internal_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Ki </ci>
  </apply>
  <apply><times />
    <apply><minus />
      <apply><plus />
        <ci> i_CaK </ci>
        <ci> i_Kr </ci>
        <ci> i_Ks </ci>
        <ci> i_KNa </ci>
        <ci> i_Kl </ci>
        <ci> i_K_ATP </ci>
        <ci> i_Kp </ci>
        <ci> i_ns_K </ci>
      </apply>
      <apply><minus />
        <apply><times />
          <ci> i_NaK </ci>
          <cn cellml:units="dimensionless"> 2.0 </cn>
        </apply>
      </apply>
    </apply>
  </apply>
  <apply><divide />
    <ci> A_cap </ci>
    <apply><times />
      <ci> V_myo </ci>
      <ci> F </ci>
    </apply>
  </apply>
</apply>
</apply>
</apply>
</apply>

<apply id="potassium_external_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Ko </ci>
  </apply>
  <apply><times />
    <apply><plus />
      <ci> i_CaK </ci>
      <ci> i_Kr </ci>
      <ci> i_Ks </ci>
      <ci> i_KNa </ci>
      <ci> i_K_ATP </ci>
      <ci> i_Kl </ci>
    </apply>
  </apply>
</apply>

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```

    <ci> i_Kp </ci>
    <ci> i_ns_K </ci>
    <apply><minus />
      <apply><times />
        <ci> i_NaK </ci>
        <cn cellml:units="dimensionless"> 2.0 </cn>
      </apply>
    </apply>
  </apply>
  <apply><divide />
    <ci> A_cap </ci>
    <apply><times />
      <ci> V_cleft </ci>
      <ci> F </ci>
    </apply>
  </apply>
</apply>
</apply>

```

```

<apply id="calcium_JSR_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Ca_JSR </ci>
  </apply>
  <apply><minus />
    <apply><minus />
      <ci> i_rel </ci>
      <apply><times />
        <ci> i_tr </ci>
        <apply><divide />
          <ci> V_NSR </ci>
          <ci> V_JSR </ci>
        </apply>
      </apply>
    </apply>
  </apply>
</apply>

```

```

<apply id="calcium_NSR_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Ca_NSR </ci>
  </apply>
  <apply><minus />
    <apply><minus />
      <apply><plus />
        <ci> i_leak </ci>
        <ci> i_tr </ci>
      </apply>
      <ci> i_up </ci>
    </apply>
  </apply>
</apply>

```

```

<apply id="calcium_foot_diff_eq"><eq />
  <apply><diff />
    <bvar><ci> time </ci></bvar>
    <ci> Ca_foot </ci>
  </apply>

```

```

    <apply><times />
      <apply><minus />
        <ci> i_CaCa </ci>
      </apply>
    <apply><divide />
      <ci> A_cap </ci>
      <apply><times />
        <cn cellml:units="dimensionless"> 2.0 </cn>
        <ci> V_myo </ci>
        <ci> F </ci>
      </apply>
    </apply>
    <ci> R.A.V </ci>
  </apply>
</math>
</component>

<group>
  <relationship_ref relationship="containment" />
  <component_ref component="membrane">
    <component_ref component="fast_sodium_current" />
    <component_ref component="L_type_Ca_channel" />
    <component_ref component="T_type_Ca_channel" />
    <component_ref component="rapid_time_dependent_potassium_current" />
    <component_ref component="slow_time_dependent_potassium_current" />
    <component_ref component="time_independent_potassium_current" />
    <component_ref component="Na_Ca_exchanger" />
    <component_ref component="plateau_potassium_current" />
    <component_ref component="sodium_activated_potassium_current" />
    <component_ref component="sarcolemmal_calcium_pump" />
    <component_ref component="ATP_dependent_potassium_current" />
    <component_ref component="sodium_background_current" />
    <component_ref component="calcium_background_current" />
    <component_ref component="sodium_potassium_pump" />
    <component_ref component="non_specific_calcium_activated_current" />
    <component_ref component="ionic_concentrations" />
    <component_ref component="calcium_buffers_in_the_myoplasm" />
    <component_ref component="calcium_fluxes_in_the_SR" />
  </component_ref>
</group>

<connection>
  <map_components component_1="membrane" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="fast_sodium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="L_type_Ca_channel" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

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```
<connection>
  <map_components component_1="T_type_Ca_channel" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="rapid_time_dependent_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="slow_time_dependent_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="time_independent_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="ATP_dependent_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="Na_Ca_exchanger" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="plateau_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="sodium_activated_potassium_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="sarcolemmal_calcium_pump" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="sodium_background_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>
```

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<connection>
  <map_components component_1="calcium_background_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="sodium_potassium_pump" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="non_specific_calcium_activated_current" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="ionic_concentrations" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="calcium_buffers_in_the_myoplasm" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="calcium_fluxes_in_the_SR" component_2="environment" />
  <map_variables variable_1="time" variable_2="time" />
</connection>

<connection>
  <map_components component_1="membrane" component_2="fast_sodium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Na" variable_2="i_Na" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>

<connection>
  <map_components component_1="membrane" component_2="L_type_Ca_channel" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Ca_L" variable_2="i_Ca_L" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>

<connection>
  <map_components component_1="membrane" component_2="T_type_Ca_channel" />

```

```
<map_variables variable_1="V" variable_2="V" />
<map_variables variable_1="i_Ca_T" variable_2="i_Ca_T" />
<map_variables variable_1="R" variable_2="R" />
<map_variables variable_1="T" variable_2="T" />
<map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="rapid_time_dependent_potassium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Kr" variable_2="i_Kr" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="slow_time_dependent_potassium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Ks" variable_2="i_Ks" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="sodium_activated_potassium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_KNa" variable_2="i_KNa" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="Na_Ca_exchanger" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_NaCa" variable_2="i_NaCa" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="ATP_dependent_potassium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_K_ATP" variable_2="i_K_ATP" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
```

```
<map_components component_1="membrane" component_2="time_independent_potassium_current" />
<map_variables variable_1="V" variable_2="V" />
<map_variables variable_1="i_K1" variable_2="i_K1" />
<map_variables variable_1="R" variable_2="R" />
<map_variables variable_1="T" variable_2="T" />
<map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="plateau_potassium_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Kp" variable_2="i_Kp" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="sarcolemmal_calcium_pump" />
  <map_variables variable_1="i_p_Ca" variable_2="i_p_Ca" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="sodium_background_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Na_b" variable_2="i_Na_b" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="calcium_background_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_Ca_b" variable_2="i_Ca_b" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="sodium_potassium_pump" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="i_NaK" variable_2="i_NaK" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="non_specific_calcium_activated_current" />
  <map_variables variable_1="V" variable_2="V" />
  <map_variables variable_1="R" variable_2="R" />
  <map_variables variable_1="T" variable_2="T" />
  <map_variables variable_1="F" variable_2="F" />
  <map_variables variable_1="i_ns_Ca" variable_2="i_ns_Ca" />
</connection>
```

```
<connection>
  <map_components component_1="membrane" component_2="ionic_concentrations" />
  <map_variables variable_1="F" variable_2="F" />
</connection>
```

```
<connection>
  <map_components component_1="fast_sodium_current" component_2="ionic_concentrations" />
  <map_variables variable_1="i_Na" variable_2="i_Na" />
  <map_variables variable_1="Nao" variable_2="Nao" />
  <map_variables variable_1="Nai" variable_2="Nai" />
</connection>
```

```
<connection>
  <map_components component_1="L_type_Ca_channel" component_2="ionic_concentrations" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Cao" variable_2="Cao" />
  <map_variables variable_1="Nao" variable_2="Nao" />
  <map_variables variable_1="Nai" variable_2="Nai" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="i_CaCa" variable_2="i_CaCa" />
  <map_variables variable_1="i_CaNa" variable_2="i_CaNa" />
  <map_variables variable_1="i_CaK" variable_2="i_CaK" />
</connection>
```

```
<connection>
  <map_components component_1="L_type_Ca_channel" component_2="calcium_fluxes_in_the_SR" />
  <map_variables variable_1="i_Ca_L" variable_2="i_Ca_L" />
</connection>
```

```
<connection>
  <map_components component_1="T_type_Ca_channel" component_2="ionic_concentrations" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Cao" variable_2="Cao" />
  <map_variables variable_1="i_Ca_T" variable_2="i_Ca_T" />
</connection>
```

```
<connection>
  <map_components component_1="T_type_Ca_channel" component_2="calcium_fluxes_in_the_SR" />
  <map_variables variable_1="i_Ca_T" variable_2="i_Ca_T" />
</connection>
```

```
<connection>
  <map_components component_1="rapid_time_dependent_potassium_current" component_2="ionic_c" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="i_Kr" variable_2="i_Kr" />
</connection>
```

```
<connection>
  <map_components component_1="slow_time_dependent_potassium_current" component_2="ionic_c" />
  <map_variables variable_1="Ki" variable_2="Ki" />
</connection>
```

```
<map_variables variable_1="Ko" variable_2="Ko" />
<map_variables variable_1="Nai" variable_2="Nai" />
<map_variables variable_1="Nao" variable_2="Nao" />
<map_variables variable_1="Cai" variable_2="Cai" />
<map_variables variable_1="i_Ks" variable_2="i_Ks" />
</connection>
```

```
<connection>
  <map_components component_1="ATP_dependent_potassium_current" component_2="ionic_concentrations" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="i_K_ATP" variable_2="i_K_ATP" />
</connection>
```

```
<connection>
  <map_components component_1="sodium_activated_potassium_current" component_2="ionic_concentrations" />
  <map_variables variable_1="Nai" variable_2="Nai" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="i_KNa" variable_2="i_KNa" />
</connection>
```

```
<connection>
  <map_components component_1="Na_Ca_exchanger" component_2="ionic_concentrations" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Nai" variable_2="Nai" />
  <map_variables variable_1="Cao" variable_2="Cao" />
  <map_variables variable_1="Nao" variable_2="Nao" />
  <map_variables variable_1="i_NaCa" variable_2="i_NaCa" />
</connection>
```

```
<connection>
  <map_components component_1="Na_Ca_exchanger" component_2="calcium_fluxes_in_the_SR" />
  <map_variables variable_1="i_NaCa" variable_2="i_NaCa" />
</connection>
```

```
<connection>
  <map_components component_1="time_independent_potassium_current" component_2="ionic_concentrations" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="i_K1" variable_2="i_K1" />
</connection>
```

```
<connection>
  <map_components component_1="plateau_potassium_current" component_2="ionic_concentrations" />
  <map_variables variable_1="i_Kp" variable_2="i_Kp" />
</connection>
```

```
<connection>
  <map_components component_1="sarcolemmal_calcium_pump" component_2="ionic_concentrations" />
  <map_variables variable_1="i_p_Ca" variable_2="i_p_Ca" />
  <map_variables variable_1="Cai" variable_2="Cai" />
</connection>
```

```

</connection>

<connection>
  <map_components component_1="sodium_background_current" component_2="ionic_concentrations" />
  <map_variables variable_1="i_Na_b" variable_2="i_Na_b" />
</connection>

<connection>
  <map_components component_1="calcium_background_current" component_2="ionic_concentration" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Cao" variable_2="Cao" />
  <map_variables variable_1="i_Ca_b" variable_2="i_Ca_b" />
</connection>

<connection>
  <map_components component_1="sodium_potassium_pump" component_2="ionic_concentrations" />
  <map_variables variable_1="Nai" variable_2="Nai" />
  <map_variables variable_1="Nao" variable_2="Nao" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="i_NaK" variable_2="i_NaK" />
</connection>

<connection>
  <map_components component_1="non_specific_calcium_activated_current" component_2="ionic_c" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Cao" variable_2="Cao" />
  <map_variables variable_1="Nao" variable_2="Nao" />
  <map_variables variable_1="Nai" variable_2="Nai" />
  <map_variables variable_1="Ko" variable_2="Ko" />
  <map_variables variable_1="Ki" variable_2="Ki" />
  <map_variables variable_1="i_ns_Na" variable_2="i_ns_Na" />
  <map_variables variable_1="i_ns_K" variable_2="i_ns_K" />
</connection>

<connection>
  <map_components component_1="calcium_buffers_in_the_myoplasm" component_2="ionic_concentrations" />
  <map_variables variable_1="Cai" variable_2="Cai" />
</connection>

<connection>
  <map_components component_1="calcium_fluxes_in_the_SR" component_2="ionic_concentrations" />
  <map_variables variable_1="i_rel" variable_2="i_rel" />
  <map_variables variable_1="i_tr" variable_2="i_tr" />
  <map_variables variable_1="i_leak" variable_2="i_leak" />
  <map_variables variable_1="i_up" variable_2="i_up" />
  <map_variables variable_1="Cai" variable_2="Cai" />
  <map_variables variable_1="Ca_JSR" variable_2="Ca_JSR" />
  <map_variables variable_1="Ca_NSR" variable_2="Ca_NSR" />
</connection>

</model>

```