

# Numerical Representation of Planetary Ephemerides

X. X. Newhall, Celestial Mechanics 45:305-310, 1989

## Computations

A handy function to compute the derivative of a Chebyshev polynomial.

```
In[239]:= DChebyshevT = Derivative[0, 1][ChebyshevT]
```

```
Out[239]= ChebyshevU[-1 + #1, #2] #1 &
```

This function computes matrix  $T$  from Newhall's equation (5). The parameter degree is the degree of the polynomial ( $N$  in Newhall), the parameter divisions is the number of subintervals of  $[-1, 1]$  (8 in Newhall).

```
In[240]:= NewhallT[degree_Integer, divisions_Integer] :=  
  Flatten[  
    Table[  
      {Table[ChebyshevT[j, i], {j, 0, degree}],  
       Table[DChebyshevT[j, i], {j, 0, degree}]},  
      {i, 1, -1, -2/divisions}],  
    {1, 2}]
```

This function computes matrix  $W$  used in Newhall's equation (8). The parameter  $w$  is the weight of the velocities relative to the positions (0.4 in Newhall).

```
In[241]:= NewhallW[divisions_Integer, w_Rational] :=  
  DiagonalMatrix[Flatten[Table[{1, w^2}, {divisions + 1}]]]
```

The following functions compute the four blocks of matrix  $C1$  and assemble them to form  $C1$ .

```
In[242]:= NewhallC1UpperLeft[degree_Integer, divisions_Integer, w_Rational] :=  
  NewhallT[degree, divisions]^T.NewhallW[divisions, w].NewhallT[degree, divisions]
```

```
In[243]:= NewhallC1UpperRight[degree_Integer] :=  
  Table[{ChebyshevT[i, 1], DChebyshevT[i, 1],  
         ChebyshevT[i, -1], DChebyshevT[i, -1]}, {i, 0, degree}]
```

```
In[244]:= NewhallC1LowerLeft[degree_Integer] := NewhallC1UpperRight[degree]^T
```

```
In[245]:= NewhallC1LowerRight[] := Table[0, {4}, {4}]
```

```
In[246]:= NewhallC1[degree_Integer, divisions_Integer, w_Rational] :=
  ArrayFlatten[
    {{NewhallC1UpperLeft[degree, divisions, w], NewhallC1UpperRight[degree]},
     {NewhallC1LowerLeft[degree], NewhallC1LowerRight[[]]}}
```

The following functions compute the two blocs of matrix C2 and assemble them to form C2.

```
In[247]:= NewhallC2Upper[degree_Integer, divisions_Integer, w_Rational] :=
  NewhallT[degree, divisions]^T.NewhallW[divisions, w]
```

```
In[248]:= NewhallC2Lower[divisions_Integer] :=
  Drop[IdentityMatrix[2 divisions + 2], {3, 2 divisions}]
```

```
In[249]:= NewhallC2[degree_Integer, divisions_Integer, w_Rational] := ArrayFlatten[
  {{NewhallC2Upper[degree, divisions, w]}, {NewhallC2Lower[divisions]}}
```

This function computes the matrix  $C1^{-1}.C2$ . Newhall doesn't give it a name but calls its elements  $c_k$ , so let's use the name C.

```
In[250]:= NewhallC[degree_Integer, divisions_Integer, w_Rational] :=
  Inverse[NewhallC1[degree, divisions, w]].NewhallC2[degree, divisions, w]
```

## Formatting and Output

Produces a representation of a matrix as an initializer\_list containing initializer\_lists.

```
In[251]:= BidimMatrixToCDefinition[type_String, variable_String, matrix_List] :=
  type <> " const\r\n      " <> variable <> "(\r\n" <>
  StringReplace[
    ToString[CForm[matrix]],
    {"List(List(" → "      {"",
     "List(" → "{",
     ")", " → "}, \r\n      ",
     ", " → ", \r\n      ",
     ")))" → "}); \r\n\r\n"}]
```

Produces a representation of a matrix as a single, flattened initializer list.

```
In[252]:= FlattenedMatrixToCDefinition[type_String, variable_String, matrix_List] :=
  type <> " const\r\n      " <> variable <> "(\r\n" <>
  StringReplace[
    ToString[CForm[matrix]],
    {"List(List(" → "      {"",
     "List(" → "\r\n      ",
     ")", " → ", \r\n",
     ", " → ", \r\n      ",
     ")))" → "}); \r\n\r\n"}]
```

Produces a representation of a list as an initializer list.

```
In[253]:= ListToCDefinition[type_String, variable_String, list_List] :=
  type <> " const\r\n      " <> variable <> "(\r\n" <>
  StringReplace[
    ToString[CForm[list]],
    {"List(" → "      {",
     ", " → ", \r\n      ",
     ")" → "});\r\n\r\n"}]
```

Writes all the Newhall C matrices to a single file. Note that we drop the last 4 rows because they correspond to the Lagrange multipliers.

```
In[254]:= file =
  OpenWrite[
    FileNameJoin[{DirectoryName[NotebookDirectory[]], "numerics",
      "newhall.mathematica.cpp"}], BinaryFormat → True, PageWidth → Infinity];
  WriteString[
    file,
    "// Generated by the Mathematica. DO NOT EDIT!\r\n",
    "// source: mathematica/newhall.nb\r\n",
    "\r\n",
    "#pragma once\r\n",
    "\r\n",
    "#include \"numerics/fixed_arrays.hpp\"\r\n",
    "\r\n",
    "namespace principia {\r\n",
    "namespace numerics {\r\n",
    Do[
      WriteString[
        file,
        FlattenedMatrixToCDefinition[
          "FixedMatrix<double, " <> ToString[degree] <> " + 1, 2 * 8 + 2>",
          "newhall_c_matrix_degree_" <> ToString[degree] <> "_divisions_8_w04",
          Drop[NewhallC[degree, 8, 4/10], -4]]],
      {degree, 3, 17}];
    WriteString[
      file,
      "} // namespace numerics\r\n",
      "} // namespace principia\r\n";
  Close[file];
```

Save a pdf printout of this file for documentation purposes.

```
In[259]:= printout = FileNameJoin[
  {DirectoryName[NotebookDirectory[]], "documentation", "newhall.pdf"}];
  NotebookPrint[EvaluationNotebook[], printout]
```