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AUTOMATING RETRIEVAL OF EARTH ORIENTATION PREDICTIONS

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As the range of applications requiring knowledge of UT1-UTC increases, the demand for access to this information in a machine readable format over the internet will increase. The current format, the text of the IERS Bulletin A, is not ideally suited to this purpose for a number of reasons. The exact format of the file is not defined so that anyone writing a program that extracts information from the bulletin has to guess the rules governing the format by inspecting samples. Any such program is at risk if, for any reason the format changes. This paper explores whether there are alternatives to Bulletin A that would be more suitable for ingestion by computer systems and could be implemented within the resources available to the IERS. Suitable standards-based technologies exist but must have both a long expected lifetime and be practical to implement both for the producer and the consumer. A concrete proposal based on XML standards is included.

INTRODUCTION

There are some real-time control applications that require information about the earth's orientation; most obviously, the control systems of astronomical telescopes. This information comes from the IERS predictions of UT1-UTC and polar motions as published in Bulletin A. A typical operational scenario is for the telescope operator to look up UT1-UTC for the current date and type it into a computer at the start of the night. This is a relatively minor step in the, often complex, process of getting the telescope ready for observing, carried out under time pressure and at some observatories, at high altitude. There are obviously opportunities for errors in this process, such as picking the wrong date, or, if there are technical problems demanding the operator's attention, the step may be overlooked altogether. Fortunately, the consequences are usually not particularly serious, typically just a small error in the telescope pointing and worst that can happen is that there is a short delay in getting observing under way. UT1-UTC changes sufficiently slowly that entering a new value can be neglected for days or even weeks, before the error becomes significant (provided of course that the control system retains the current value when the system is re-started).

An experienced telescope operator knows the valid range for UT1-UTC and plausible values for the polar motions (where required, many systems ignore them as they are only marginally significant for ground-based telescopes and only then for telescopes with the very best pointing accuracy achievable) so the chances of making a gross error are small. However, as observatory

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budgets come under every increasing pressure it is becoming more and more common for, even quite large, telescopes to no longer have a dedicated operator. The task of readying the system is then in the hands of an astronomer, often a visitor to the observatory and so working in an unfamiliar environment and who may operate a telescope only a few times a year. The chances of an error occurring clearly becomes greater and the time taken to recover becomes longer.

The opportunity for error can be all but eliminated by having the control system retrieve the current value of UT1-UTC from the IERS without operator intervention and, in the case of a robotic telescope, where there is not operator at all, it is essential. However, the current format of the IERS Bulletin A, is not ideally suited to this purpose for a number of reasons. The exact format of the file is not defined (at least, not in an easily discoverable place) so anyone writing a program that extracts information from the bulletin has to guess the rules governing the format by inspecting sample bulletins. Any such program may fail if, for any reason the format changes. As long as leap seconds keep UT1-UTC less than 0.9 seconds, the validity of the input can be checked so that most errors can be detected but if this constraint is removed, checking for errors becomes much more difficult.

As UTC (or whatever civil time is called in the future) drifts away from the rotation of the earth, the range of applications which requires knowledge of UT1-UTC will increase, and along with it, demand for access to this information in a machine readable format over the internet. Also, Bulletin A contains more than just UT1-UTC and is somewhat intimidating for the non-specialist. A programmer who is told that UT1-UTC is needed and is given the URL of the Bulleting A is likely to be a bit uncertain as to whether the column labeled UT1-UTC is, in fact, all they need or whether other information contained in the bulletin is somehow relevant. All the necessary explanatory information is available on the IERS web site but in too much detail for the non-specialist to comprehend easily.

Once UT1-UTC is being imported into a software system automatically, the consequences of the process failing in some way have to be considered. In particular, the case where the failure goes undetected and an erroneous value is inserted into the system. If a safety critical system could be disrupted by a corrupted copy of the bulletin then any new way of distributing earth orientation predictions must have the necessary safeguards built in.

Any such new way of distributing earth orientation predictions ought to be straight-forward to use and accessible to the widest possible audience using readily available tools and well known techniques. It must also be implementable with the resources available to the IERS. The obvious mechanism is a text file that can be copied with the http protocol.

FILE DESIGN

Format

There can be little argument that the most appropriate file format for this application is XML[*] because it is:

- Defined by a mature and stable internationally recognized standard.
- Widely deployed across practically all applications areas.

[*] http://www.w3.org/TR/REC-xml/

- A wide range of tools for creating, reading and manipulating XML are available, many of them free, and on all commonly used operating systems.
- It can be interpreted by humans as well as by computer programs.
- It is unlikely to be superseded in the foreseeable future.
- The family of XML standards includes a specification for digital signing

XML is, of course, not perfect. It can be wasteful of space and expensive to parse in comparison with some other formats and it is clumsy to edit by hand. It also looks fairly ugly. However, none of these criticisms are particularly relevant for the application being proposed here.

XML is extremely flexible and distinguishing between a good design and a bad design is not easy. The principles adopted here are to keep things as simple as possible and to favor ease of parsing by a computer over readability. The latter implies using element properties rather than text elements for the data.

Content

The following example is valid XML and contains the about minimum necessary to achieve the stated purpose without being overly cryptic:

```
<earth_rotation_prediction_table>
  <earth_rotation date="2011-07-02" x="0.1714" y="0.4109" UT1-UTC="-0.30187"/>
  <earth_rotation date="2011-07-03" x="0.1727" y="0.4099" UT1-UTC="-0.30234"/>
  <earth_rotation date="2011-07-04" x="0.1739" y="0.4088" UT1-UTC="-0.30289"/>
  <earth_rotation date="2011-07-05" x="0.1750" y="0.4077" UT1-UTC="-0.30351"/>
  <earth_rotation date="2011-07-06" x="0.1759" y="0.4065" UT1-UTC="-0.30417"/>
</earth_rotation_prediction_table>
```

However, for a document that is going to be distributed outside a single organization some additional content is desirable such as:

- An XML declaration
- An indication of where the information it contains originates
- A reference to a source of explanatory information about the file contents
- A reference to an XML schema that formally defines the structure

Other improvements that can be considered are to make the units of UT1-UTC and the polar motions explicit, to encode the dates as Modified Julian Dates in addition to calendar dates and to specify the range of dates covered by the table. Finally, the element and property names should be placed in a namespace in case they conflict with names in other XML documents it might be merged with. This expands the example above to (the names chosen for the namespace and schema location are for illustration only):

```
<?xml version="1.0" standalone="yes"?>
<earth_rotation_prediction
        start_date="2011-09-09"
        end_date="2011-09-13"
        xmlns ="http://www.iers.org/xbulletins"
        xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance”
        xsi:schemaLocation=
                "http://www.iers.org/xbulletins Earth_Rotation_Prediction.xsd">
    <source
       url="http://data.iers.org/products/6/14858/orig/bulletina-xxiv-036.txt">
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```

```
    </source>
    <reference url="http://maia.usno.navy.mil/bullainfo.html"/>
    <reference url="http://hpiers.obspm.fr/iers/bul/bulb/explanatory.html"/>
    <earth_rotation_prediction_table>
        <earth_rotation date="2011-09-09" MJD="55813"
                x_arcsec="0.1714" y_arcsec="0.4109" UT1-UTC_sec="-0.30187"/>
        <earth_rotation date="2011-09-10" MJD="55814"
                x_arcsec="0.1727" y_arcsec="0.4099" UT1-UTC_sec="-0.30234"/>
        <earth_rotation date = "2011-09-11" MJD ="55815"
                x_arcsec="0.1739" y_arcsec="0.4088" UT1-UTC_sec="-0.30289"/>
        <earth_rotation date="2011-09-12" MJD="55816"
            x_arcsec="0.1750" y_arcsec="0.4077" UT1-UTC_sec="-0.30351"/>
        <earth_rotation date="2011-09-13" MJD ="55817"
            x_arcsec="0.1759" y_arcsec="0.4065" UT1-UTC_sec="-0.30417"/>
    </earth_rotation_prediction_table>
</earth_rotation_prediction>
```

The impact on the readability of adding more material is plain to see and, although it is easy to think of more that could be added, a balance has to be struck between what might be relevant to someone reading the file and obscuring the original purpose.

This format can be formally specified by an XML schema such as:

```
<?xml version="1.0"?>
<xs:schema elementFormDefault="qualified"
           xmlns:xs=http://www.w3.org/2001/XMLSchema
           targetNamespace="http://www.iers.org/xbulletins">
    <xs:element name="earth_rotation_prediction">
        <xs:complexType>
            <xs:sequence>
                <xs:element ref="source"/>
                <xs:element ref="reference" maxOccurs="unbounded"/>
                <xs:element ref="earth_rotation_prediction_table"/>
            </xs:sequence>
            <xs:attribute name="start_date" type="xs:date"
                          use="required"/>
            <xs:attribute name="end_date" type="xs:date"
                          use="required"/>
        </xs:complexType>
        </xs:element>
        <xs:element name="earth_rotation">
            <xs:complexType>
                <xs:attribute name="date" type="xs:string"
                              use="required"/>
                <xs:attribute name="MJD" type="xs:string"
                              use="required"/>
                <xs:attribute name="x_arcsec" type="xs:string"
                              use="required"/>
                <xs:attribute name="y_arcsec" type="xs:string"
                              use="required"/>
                <xs:attribute name="UT1-UTC_sec" type="xs:string"
                              use="required"/>
            </xs:complexType>
        </xs:element>
        <xs:element name="earth_rotation_prediction_table">
            <xs:complexType>
                <xs:sequence>
                    <xs:element ref="earth_rotation"
                                maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:complexType>
        </xs:element>
```

```
        <xs:element name="reference">
            <xs:complexType>
                <xs:attribute name="url" type="xs:anyURI"
                              use="required"/>
            </xs:complexType>
            </xs:element>
            <xs:element name="source">
            <xs:complexType>
            <xs:simpleContent>
                <xs:extension base="xs:string">
                    <xs:attribute name="url" type="xs:anyURI"
                                  use="required"/>
                </xs:extension>
            </xs:simpleContent>
        </xs:complexType>
    </xs:element>
</xs:schema>
```

This is more prescriptive than is strictly necessary; it forbids any other content and constrains the order of the element. With more work, a specification that guarantees the presence and format of the earth rotation prediction table element but gives more flexibility for the rest of the file could be developed.

DIGITAL SIGNING

If earth orientation information is going to be used by safety critical systems, a mechanism for assuring the integrity of this information must be implemented. The technology for doing this is digital signing using a public/private key infrastructure. The standard for signing XML documents is defined by the WC3 recommendation "XML-Signature Syntax and Processing". [*] Only a small number of organizations will be interested in checking the integrity of earth rotation predictions so the ease with which a signature can be verified is not particularly important; the few who need to verify it can be assumed to be knowledgeable about the processes involved. However, signing a document has to be sufficiently straight-forward to be practical for the IERS and the result should be as unobtrusive as possible for those not interested in the signature.

The WC3 recommendation describes several alternative structures for a signed XML document.

- The signature can be contained within (be a child of) the material being signed.
- The signature can contain the material to be signed (the signature is the parent of the signed material).
- The signature can be alongside (a sibling of) the signed material
- The signature can reside in another document entirely

Putting the signature in a separate document is the least intrusive option as the only addition to the format shown above would be a reference to the location of the signature, but it does require more administration; there is an additional file to manage and if files are moved additional steps are need to maintain the link from the document to the signature. Embedding the document in the signature alters the steps needed to access the table and makes it harder to strip out the signature if it is not required. Both of the remaining options are equally suitable.

[*] http://www.w3.org/TR/2002/REC-xmldsig-core-20020212/

Free software is available for both signing and verifying signatures (for example, the Java software development kit from Oracle) but some programming is required. A certificate issued by a recognized certificate authority is also need; ideally one issued by an authority who's root certificate is installed by operating system manufacturers so that if, in the future, software tools verify signatures by default, warnings about missing certificates will not be generated.

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