PERSPECTIVES FOR OPEN SKIES: TECHNICAL, OPERATIONAL AND POLITICAL ASPECTS *

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ABSTRACT

The Treaty on Open Skies of March 1992 aims at improving openness and transparency among its member states, in order to strengthen peace, stability and security. It foresees observation overflights over the full territory of 27 states parties in North America, Europe and Asia (NATO states and members of the former Warsaw Treaty Organisation). The agreed sensor set includes photographic cameras at 30 cm ground resolution, thermal infrared scanners at 50 cm ground resolution and synthetic aperture radar at 3 m ground resolution. Although the Treaty has not yet entered into force, an intensive trial operation program has been initiated, which has provided considerable operational experience. In this contribution we will address results from trial operation and the outlook for Treaty ratification. We also verify that images at the agreed photographic resolution cannot be sharpened by image transformations. Finally we discuss the perspectives for implementing the Open Skies approach in other regions of the World.

1 OBJECTIVES AND TREATY PROVISIONS

The Open Skies Treaty is one of the most encompassing confidence building measures agreed upon so far. It was negotiated in the wake of the East-West-conflict (1989-1992) (Jones 1991). It includes 27 state parties from 'Vancouver to Vladivostok', in particular the then 16 NATO states (1992) as well as Belarus, Bulgaria, the Czech Republic, Georgia, Hungary, Kyrgyzstan, Poland, Romania, Russia, Slovakia and Ukraine.
The objectives of the Treaty - as stated in the preamble - are

- to improve openness and transparency,
- to facilitate monitoring and compliance with existing or future arms control agreements and
- to strengthen the capacity for conflict prevention and crisis management in the framework of the Conference on Security and Co-operation in Europe (CSCE) and other relevant international institutions.

The Treaty is thus primarily oriented towards military security and arms control. The implementation of the Treaty is executed by military staff. However, the preamble envisages also "the possible extension of the Open Skies regime into additional fields, such as the protection of the environment". The materialization of this option would require further negotiations. It seems to be common understanding among the state parties that steps in this direction will not be taken before entry into force of the Treaty (Spitzer 1997).

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The most remarkable feature of the Treaty is the *opening of the full airspace* of the state parties to overflights by unarmed observation aircraft. Hence for the first time the regions of North America and the russian territory beyond the Urals are becoming accessible to unrestricted aerial inspection. Another innovative element of the Treaty is the *openness of the image data*. Copies of the image data are available at nominal cost to all state parties. However, although unclassified, data will be accessible to state agencies only, for purposes in accord with the Treaty. Hence, there are limits to openness.
Other provisions of the Treaty are as follows (Spitzer 1996):

- The agreed *imaging sensors* are
  - optical panoramic and framing cameras with a ground resolution of 30 cm,
  - video cameras with real-time display and a ground resolution of 30 cm,
  - thermal infrared imaging sensors with a ground resolution of 50 cm at $\Delta T = 3°C$ (temperature resolution), and
  - imaging radar (Synthetic Aperture Radar, SAR) with ground resolution of 300 cm.

  This establishes an all-weather, day-and-night monitoring capability. Sensors have to be commercially available to the state parties. Note that the resolution definition for the photographic systems is not the standard photogrammetric definition. The Treaty resolution is approximately equivalent to a pixel resolution of 30 cm of a electro-optic sensor. For further information on sensors and sensor resolution see e.g. (Spitzer 1996), (Simmons 1996).

- The *recording media* will be (a) black-and-white film for photographic cameras, (b) magnetic tape for video cameras, (c) black-and-white photographic film or magnetic tape for thermal infrared sensors, and (d) magnetic tape for radar.

- Overflights are being alotted according to a *quota system*, which takes consideration of the geographic area of a country. Overflights can be carried out upon short notice. The observed state has a minimum of 24 hours advance notice between accepting the mission plan and the observation flight. The flights are cooperative with staff from at least two states onboard.

- Each aircraft and sensor has to be *certified* before Treaty operation, in order to verify that it conforms to the provisions of the Treaty. A particular concern is the adherence to the resolution limits set by the Treaty.

- A joint commission, the *Open Skies Consultative Commission* (OSCC), supports the implementation and further development of the Treaty and arrives at decisions by consensus. The commission meets in Vienna at the OSCE headquarters.

2 PREPARATIONS FOR IMPLEMENTATION

The Treaty was signed on 24 March 1992 in Helsinki. It has been ratified by most of the state parties except for Belarus, Kyrgyzstan, the Russian Federation and Ukraine. The ratifications by Belarus, the Russian Federation and Ukraine are required before the Treaty can enter into force. In spite of this, most state parties have taken manifold preparation steps for the implementation of the Treaty. 23 states have established active *operation units* and a training program, which is intended to prepare equipment and to train personel for Treaty operations.
Several nations have modified existing aircraft specifically for Open Skies use. The aircraft comprise
(a) twin engine aircraft of medium range (about 1500 km): AN30 (Bulgaria, Czechia, Romania, Russia, Ukraine), AN26 (Hungary), CN235 CASA (Turkey, planned), Andover PR MK1 (UK)
(b) long distance aircraft: 3 OC-135 (USA), C130 Hercules (pod group, see below), TU-154M (Germany, option, the first german aircraft crashed in 1997), TU-154M (Russia, option)

A group of 10 states, the so called pod-group (Belgium, Canada, France, Greece, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain) have jointly pursued the development of a sensor pod to be installed under a C-130

Table 1: Existing and planned Open Skies sensors

State	vertical framing camera	oblique framing camera	panoramic camera	video camera	infrared line scanner	radar
Bulgaria	1	-	1	1	1	-
Czech Republic	1	-	-	-	-	-
Germany	1[2]	2[2]	1	3[2]	1	1
Hungary	1	-	-	1	-	-
Romania	1	-	-	1	-	-
Russia and Belarus	1	2	1	1	1[2]	1
Turkey	1[2]	-	-	-	-	-
Ukraine	2	-	-	-	-	-
United Kingdom	1	-	1	1	1[3]	-
United States	1	2	1	1	1	1
Pod group	1	2	1	2	-	-

Hercules aircraft. This concept allows for any like model C-130 to be used for Open Skies observation missions. The pods are boxes containing initially optical and video cameras only.

All participating aircraft will be equipped with photographic framing cameras. Several states will also use a wide-angle panoramic camera. Germany, Russia, and the United States are testing or planning *thermal infrared line scanners*.[1] Germany and Russia are jointly developing a Russian-made *synthetic aperture radar system* (SAR), whereas the US is refurbishing an older SAR system of their own (Fortner & Hezeltine 1996). Table 1 gives an overview of existing and planned sensors for Open Skies missions.

3 TRIAL FLIGHTS AND TEST CERTIFICATIONS

3.1 TRIAL FLIGHTS

Although the Treaty formally has not entered into force a remarkable practice of trial flights has been initiated which brings life to the intentions of the Treaty. Many of the state parties have agreed to perform joint voluntary trial flights on a binational or multinational basis under Treaty conditions. Such flights yield both valuable operational experience and useful image data. By end 1998 186 international flights have been performed. Germany has been particularly active with a share of 60 flights. The bulk of the data is black-and-white photographs.

3.2 TEST CERTIFICATIONS

The treatment of sensor resolution is indicative of the Treaty's dual character between Cold War military thinking and a new openness. Whereas civilian remote sensing practitioners will be happy when a sensor exceeds the design resolution, Open Skies negotiators desperately tried to avoid this. A lot of effort has to be spent in proving that a sensor does not exceed the resolution specified by the Treaty.[4] This is to be accomplished in an initial seven-day *certification* of each Open Skies aircraft and by a short *demonstration flight* at the beginning of an Open Skies

[1] Infrared line scanners and radar can be used for Treaty application only three years after its entry into force.
[2] planned (decision pending)
[3] optional
[4] A subgroup of the OSCC has drafted a bulky Guidance Document on sensors. The current draft of 26 May 1997 runs at 300 pages.

observation mission if requested. During these tests certain calibration targets (e.g. panels with black and white bars in case of optical cameras) are displayed on the ground and recorded by the sensors on board the overflying aircraft. Subsequent processing and analysis has to prove that the resolution goals have been met. After several failures the first successful test certifications took place in 1997 (German TU-154M) and in 1998 (Hungarian AN26 and US OC-135).

Four lessons can be drawn from the trial flights and test certifications:

1. Several of the trial flights, in particular those of Germany over Russia and the Ukraine, yielded image data, which are relevant and useful from an arms control perspective.
2. The particular pod solution (1 pod for 10 countries) is rather inflexible and difficult to operate.
3. In general the Treaty provisions turned out to be practicable.
4. However the need to adhere to strict resolution limits makes the certification and the Treaty operation technically much more demanding than other confidence building measures.

The latter problem has been circumvented in the *Hungarian-Romanian bilateral Open Skies agreement* of 1991. Neither the focal length nor the ground resolution of the sensors are limited (Jones & Krasznai 1992). This eases the certification and the flight operations a lot. The Hungarian-Romanian agreement is the only Open Skies accord which has entered into force so far.

3.3 DEMONSTRATION FLIGHTS OVER BOSNIA

Early in 1997 the Hungarian Ambassador to the OSCE Marton Krasznai proposed Open Skies demonstration flights over Bosnia and Herzegovina as part of voluntary confidence building measures under the Dayton accord. Four flights were subsequently performed with foreign Open Skies aircraft, in particular

- 17/18 June 1997	Hungarian-Romanian flight with Hungarian AN26 (9 ground sites photographed)
- 27 August 1997	German flight with TU 154M (77 objects in all parts of Bosnia Herzegovina)
- 5/6 November 1997	Russian-US flight on Russian AN30 with contributions from Germany and Hungary
- 13-16 July 1998	German-Russian flight on Russian AN30 (47 objects photographed)

Both, international observers and observers from the three Bosnian (military) parties were on board. The underlying idea was to introduce the local parties to an aerial inspection regime in the spirit of Open Skies. Copies of the film were handed over to the parties. However, the parties apparently made little efforts to analyse the pictures. This triggered Germany to offer analysis equipment and a training session on image interpretation. Eventually the three parties got quite interested. Presently the parties under the supervision of the OSCE (office for regional stabilization, Sarajevo) are working out a protocol for aerial inspections with helicopters and video cameras. It is intended to have an agreement by mid 1999.

4 FLIGHTS FOR DESASTER MONITORING

As mentioned above the preamble of the Treaty foresees potential applications for the protection of the environment. In this spirit Poland and the state government of Brandenburg have asked for an observation flight of the german Open Skies aircraft during the flooding of the river Oder in July 1997. The aircraft mapped the full river area from the influx of the Neiße to the Baltic sea. The black-and-white photographs were developed during one night and were handed over to the governments of Poland and Brandenburg on the next day. Fig. 1 shows an example of the images taken.

Along similar lines one of the US Open Skies aircrafts was sent to Central America, shortly after the devastating impact of hurricane Mitch in November 1998. The territories of Honduras and Nicaragua and other areas were mapped in five missions at resolutions of 20-30 cm. Copies of the images were provided to the governments concerned and to a major US relief organization. The imagery is being used for relief and preventive measures. This underlines the potential of Open Skies assets for desaster monitoring on short notice. However, future application will depend

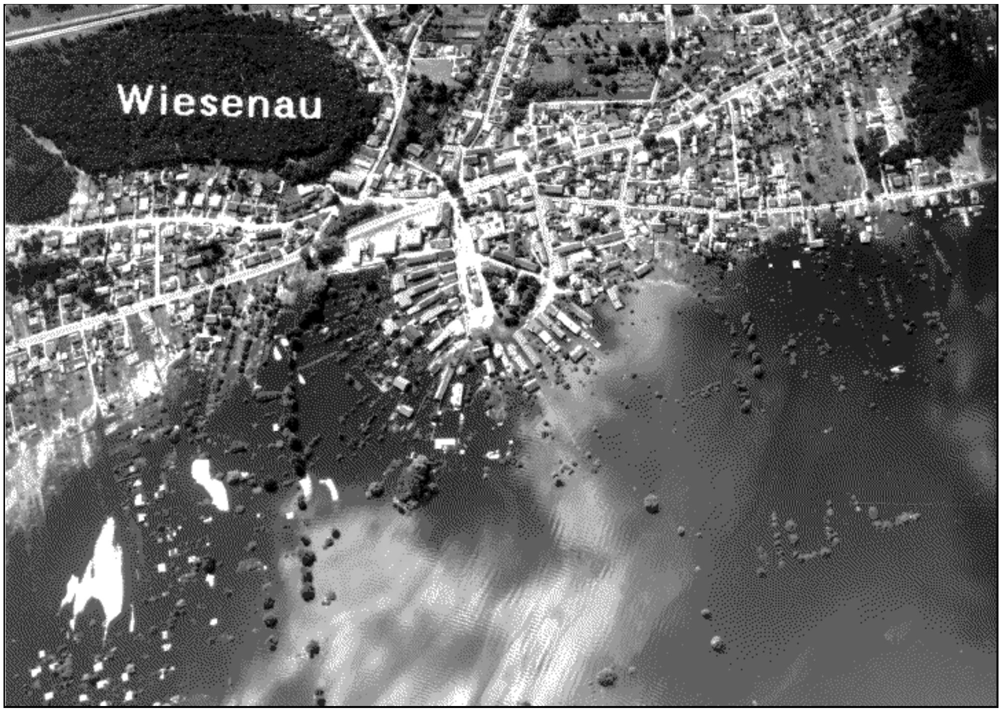

Figure 1: Oder flooding near Wiesenau as photographed from the german OS aircraft (courtesy: Zentrum für Verifikationsaufgaben der Bundeswehr)

on (a) settlement of the cost question, and (b) avoidance of competition with civilian desaster monitoring capabilities.

5 CRITICAL DEVELOPMENTS

Two critical developments are affecting the future of the Treaty. First, the german Open Skies aircraft, which had the most advanced sensor equipment among all states, was lost in an air crash over the Southern Atlantic on 13 September 1997. It remains open, whether the german Minister of Defence will give the (financial) go-ahead for the refurbishing of another TU 154M for Open Skies purposes.
Second and more important, all attempts of Treaty *rafication* in the Russian Duma and the Ukrainian Rada have failed so far. The outlook for imminent ratification is bleak. The Open Skies as well as the START II Treaties have become victims of changing priorities, political splits and deep disappointment about what is perceived in Russia as US unilateralism. The Open Skies Treaty might not survive a longtime denial of Russian ratification. After all it is competing to some extent with other confidence building measures which are in force, like the Vienna Document of 1994.

6 CAN THE IMAGES BE 'SHARPENED'?

Since so many of the technical provisions of the Treaty are motivated by the aim to limit the ground resolution of the images, the question arises whether the images can be 'sharpened' afterwards in order to circumvent the Treaty limitations. We will shortly discuss this question based on a case study on inverse and Wiener filtering.

In textbooks on image processing we find astonishing examples of *image restoration*. A typical case is the removal of blur e.g. by inverse filtering in the (Fourier transformed) frequency domain (Fig. 2 top row).

How can we be sure that this cannot be done with Open Skies imagery on a regular basis? Let us consider the example of Fig. 2. The original image (top left) is digitally blurred, using a point spread function $PSF(x) \sim exp\left(-\frac{1}{\alpha}\left\|\frac{x}{\sigma}\right\|^{\alpha}\right)$ with $\sigma = 2$ and a steepness exponent of $\alpha = 2$ (Gaussian). The blurring convolution was performed by multiplication in the Fourier transformed space (Convolution Theorem). Note that the blurring convolution is assumed to be a global transformation which affects all pixels in the same way. With the perfect knowledge of the blurring PSF and in absence of noise, the blurred image (top center) can be restored to full resolution by inverse filtering in the Fourier space. However, if the blurring process is combined with even very low noise (the superimposed noise of 1% is almost invisible to the eye), the simple inverse filtering fails completely, in that mainly the noise is amplified (Fig. 2, second row). This is a consequence of the fact that noise introduces locally varying disturbances into the image. Thus, in practise Wiener filtering (or iterative restoration or other more sophisticated methods of image restoration (Gonzalez & Wintz 1987), (Sid-Ahmed 1995), (Jähne 1997)) have to be employed. These techniques can restore some of the resolution, but the results remain clearly far from the original quality-depending on noise level. Still, note that the four engines of the airliner are not distinguishable in the blurred image but clearly visible after Wiener filtering.
The crucial point of this example is that the blur function was considerably wider than 1 pixel. In other words, the information of each pixel is smeared into the neighboring pixels, and can be 're-concentrated' by digital image processing methods. Thus in order to prevent this option it is important that the sensor has a narrow point spread function with $\sigma < 1$. In fact, we have verified that the digital video camera VOS-80 onboard of the German Open Skies aircraft (Uhl 1997) had a point spread function with $\sigma = 0.5$. The underlying data were obtained at a overflight of a ground calibration bar target as part of a test certification of the aircraft in June 1997.[5]
In summary: The images can be sharpened only if

- the point spread function (PSF) spreads considerably wider than 1 pixel and is spatially constant over the image;
- the PSF is known or can be determined with good accuracy;
- the noise level is low enough.

The PSF of the camera / sensor can be optimized such that it covers only one pixel and thus no digital image sharpening is possible. This can be verified during the certification. The atmospheric conditions could superimpose a wider PSF during the actual recording flight, but such an atmospherically induced PSF will usually not be uniform across the image and thus forbid later sharpening. In any case it is technically possible to reconstruct the actual PSF from calibration targets. If the PSF does not spread much wider than 1 pixel then it is verified that the imagery cannot be restored to better resolution later on.

7 CONCLUSIONS AND OUTLOOK

From the recent developments of the Open Skies approach the following conclusions can be drawn:

1. Although the Open Skies approach still contains remnants of Cold War suspicion, it can promote confidence building and cooperative security structures in an interesting way. In particular the elements of *equity* (equal data access for all parties) and *symbolic cooperative action* (joint flight preparation and execution) can pave the way towards a more peaceful future between participating states.

2. The only Open Skies accord in force - the bilateral Romanian-Hungarian agreement of 1991 - has demonstrated that two countries with modest technical and financial resources can create and operate a relatively effective Open Skies regime.

3. The multilateral Open Skies Treaty can be considered as a partial success, so far. Positive effects have come from the extensive trial operations. However, it is politically hampered by the lacking ratification of Russia, Ukraine and Belarus. In addition, the decrease or vanishing of mutual threat perceptions between the state parties makes Open Skies a less urgent matter for most of its members. On the other hand the Treaty still holds a potential for military and political confidence building in unstable regions of Europe. It might be useful

[5]Furthermore we were able to determine the nominal ground resolution (pixel sampling distance) from the video images of the bar target with an uncertainty of 2 mm only by digital image processing.

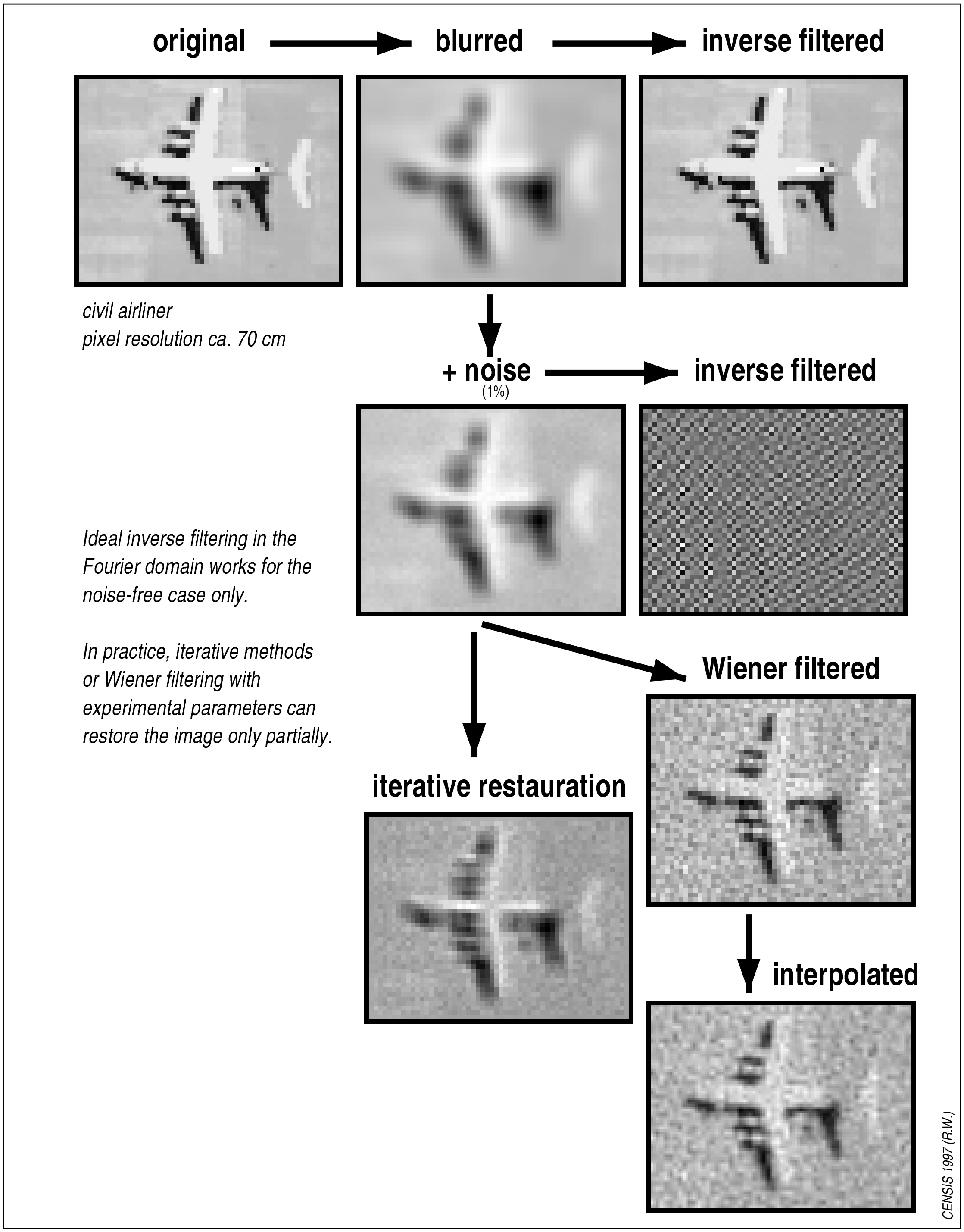

Figure 2: An example of inverse filtering and Wiener filtering of simulated blur (Gaussian, $\sigma = 2$ pixel): In absence of noise (top); and with noise (below). Note that in this simulation the blur-PSF is perfectly known. (The original image of the airliner was recorded by an airborne multispectral scanner from 300 m altitude with a pixel size of $\approx$ 70 cm at Nürnberg airport 1995 with technical support from DLR, Wessling, Germany.)

for crisis prevention and crisis management. Regional Open Skies agreements, i.e. on the Balkans or in the Caucasus region are highly desirable. The existing Open Skies assets have been and can be instrumental in supporting such regional Open Skies regimes. The forthcoming Protocol on Aerial Inspections over Bosnia and Herzegovina is a good example in case.

4. Both the bilateral and the multilateral Open Skies Treaties can serve as models for other world regions. Regions which have shown some interest in the idea include South America, Southern Asia (India, Pakistan) and South-East Asia. It remains to be seen whether the interest will transform into real agreements. When transferring the concept the technically much simpler Hungarian-Romanian agreement should be taken as a guideline (no resolution restrictions).

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