B044

CRS Stacking – A Simplified Explanation

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SUMMARY

Stacking velocity analysis and stacking is usually performed within common-midpoint gathers. Generalized approaches like the Common-Reflection-Surface stack method additionally include neighboring common-midpoint gathers to fully exploit the redundancy in the data and to extract additional stacking parameters. In many publications, the basics of the CRS stack are obscured by the uncommon parameterization. Our aim is to relate this often poorly understood approach to the established CMP-based approach in a simple and descriptive manner.

Introduction. Stacking of seismic data has been used in seismic data processing for a long time. Stack sections or volumes based on the concepts of common-midpoint (CMP) gathers and normal moveout (NMO) correction are standard deliverables in the industry. Although the general trend is towards prestack imaging, the construction of stack sections remains an important step within the seismic processing flow. This is one of the reasons why stacking methods are still being further developed, thereby taking more and more information about the subsurface into account.
One of these developments is the common-reflection-surface (CRS) stack firstly presented by Müller (1998). The CRS stack is based on the same principal ideas as the conventional CMP stack. However, it involves far more traces than those present in a CMP gather. As a direct consequence, CRS stack results usually show a dramatic increase in signal-to-noise ratio as compared to a conventional stack. As the CRS stacking formula involved lacks the simplicity of a classical CMP stack equation, the process was often also regarded as a kind of black box and many applied geophysicists have still a lot of doubts about the CRS stack. Here, we want to address these doubts by showing the basic ideas that led to the development of the CRS stack technology in a descriptive explanation. We are going to show that the CRS stack technology is nothing more than an extension of the well-known CMP stack and the related stacking velocity analysis.

CMP traveltimes. Conventional stacking velocity analysis and CMP stack are performed in individual CMP gathers. The well-known second-order traveltime function in a CMP gather reads

$$t^2 = t_0^2 + \frac{x^2}{v_{\mathrm{NMO}}^2}\,, \tag{1}$$

with zero-offset (ZO) traveltime t_0 and source-receiver offset x. The parameter v_{NMO} is known as the normal-moveout (NMO) velocity. It depends on both, the reflector dip and the medium velocity above the reflector. For complex media, the relationship between the NMO velocity and the true medium velocity can be quite obscured and may no longer allow simple Dix inversion.
For media with lateral velocity variation and/or dipping events, data within one single CMP gather do not pertain to one and the same reflection point: there is a so-called reflection-point smear which is usually considered by a dip-moveout (DMO) correction in an approximate manner. Figure 1 shows the reflection-point smear for a curved reflector. The reflection events from the different reflection points of the, say, red ray family along the reflector are collected into a single CMP gather. Thus, the reflector has to be continuous over at least that range of reflection points, just as for the DMO correction, which will remove the dip-dependent part of the reflection-point smear.

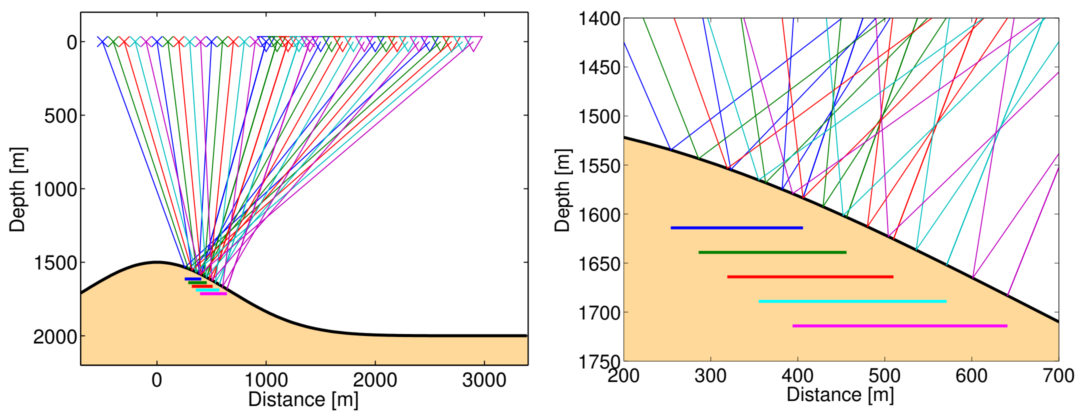

Figure 1: Ray families for five neighboring CMP gathers (left) and detail of the reflection points (right).

From CMP to CRS. According to Figure 1, neighboring CMPs dislocated from the central one share a considerable part of their reflection points with those of the central one: the horizontal bars in the respective colors indicate the part of the reflector covered by the reflection points of a certain CMP ray family. The information about this part of the reflector contained in the traces in the neighboring CMP gathers can be used to improve the final stacked trace without violating any underlying principle: even in the CMP stack we are making use of the reflector continuity.

Considering that we have to assume reflector continuity in any case, it is quite natural to stack any reflection event that was reflected on a *common reflection surface* on which an actual reflection point evidently has to be located. Although it is easier to work in CMP gathers, there is no physical reason against such an extension of the stacking zone. Leaving the single CMP gather, we are losing the beauty of the one-parametric second-order traveltime approximation given by equation (1): we have to introduce additional traveltime parameters, namely one related to the local slope of the traveltime curve at zero-offset and one that depends on its curvature. The former also enters into the NMO velocity v_{NMO}, but cannot be separated from the medium velocity using only CMP gathers. However, by introducing a new data dimension, the off-CMP or relative midpoint coordinate, both new parameters become independent. Therefore, the general traveltime function in the midpoint-offset domain depends on three independent parameters and represents a whole surface in a block of adjacent CMP gathers instead of a one-parametric curve within a single CMP gather. The second newly introduced traveltime parameter is a velocity-type parameter. However, while the NMO velocity is independent of the reflector curvature, this second velocity parameter strongly depends on this property. For this reason, we refer to it as the curvature-moveout (CMO) velocity v_{CMO}.

With these new parameters, the general traveltime formula reads

$$\begin{aligned} t^2(\Delta m, h) &= [t_0 + 2p\,\Delta m]^2 + \frac{x^2}{v_{\mathrm{NMO}}^2} + \frac{\Delta m^2}{v_{\mathrm{CMO}}^2} \\ &= \underbrace{t_0^2 + \frac{x^2}{v_{\mathrm{NMO}}^2}}_{\text{equation (1)}} + \underbrace{\frac{\Delta m^2}{v_{\mathrm{CMO}}^2}}_{\text{curv. dep.}} + \underbrace{4\,t_0\,p\,\Delta m + 4p^2\Delta m^2}_{\text{dip dependent}}\,, \end{aligned} \tag{2}$$

with the already introduced source-receiver offset x, the relative midpoint coordinate Δm, and the horizontal slowness p.

It is easy to recognize that the formula given above does not provide a new stacking concept but is in fact just an extension of the conventional hyperbolic CMP stack into the relative midpoint or off-CMP direction, thus also assuming continuity of the reflection event in this direction. It now includes additional terms depending on the dip of the reflection event and the reflector curvature. Note that the equation (2) is still a second-order approximation of traveltime. Since it describes the reflection traveltime for all points on a common reflection surface, it is referred to as the CRS traveltime. Due to the fact that it is used to stack the data, it is also referred to as the CRS stacking surface or CRS stacking operator.

In summary, the CRS stack technology is simply based on

- a parameter which defines the curvature of events with respect to offset in the central CMP gather (the well-known NMO velocity v_{NMO}),
- the slope of events at offset zero with respect to the midpoint coordinate (twice the horizontal slowness p), and
- the curvature of events at offset zero with respect to the midpoint coordinate (the curvature-moveout velocity v_{CMO}).

Generalized stacking velocity analysis. Figure 2a shows different views of a CRS stacking operator according to equation (2) determined for a real data example. The prestack data is

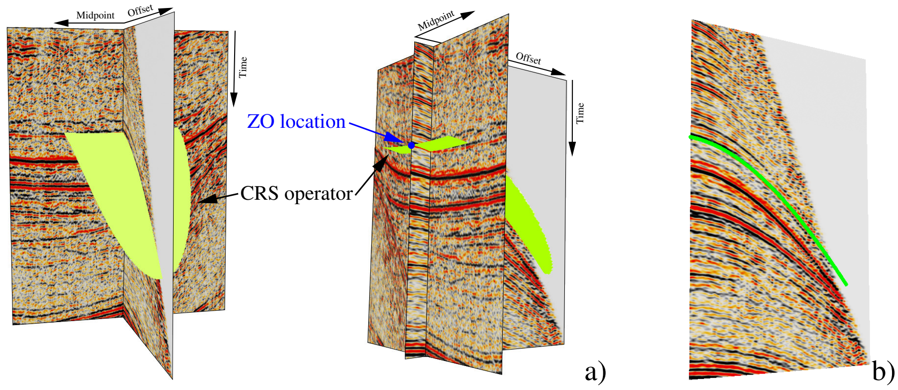

Figure 2: a) Two different views of the CRS stacking operator for a selected ZO location. The prestack data is represented by the central CMP gather and one common-offset section. The velocity v_{CMO} is imaginary for the considered concave reflection event. b) The conventional stacking operator restricted to the central CMP gather, only. The larger number of stacked traces in CRS stacking leads to an increased signal-to-noise ratio. Data courtesy of Fugro Multi Client Services.

represented by the central CMP gather and one common-offset section. Here, the CRS operator is depicted using a symmetric elliptic aperture in the midpoint/offset plane. At the ZO location to be simulated, the selected reflection event is almost horizontal and slightly curved. For comparison, Figure 2b shows the conventional stacking operator restricted to the central CMP gather. It is obvious that this conventional stacking operator is a part of the spatial CRS operator.

The determination of best-fitting CRS stacking operators to the actual reflection events in the prestack data represents a multi-dimensional generalization of the well-known stacking velocity analysis. Where conventional velocity analysis uses a stacking trajectory described by a single parameter (stacking velocity) within a CMP gather, CRS stacking uses an entire surface described by three parameters in a super-gather formed by adjacent CMP gathers. This kind of generalized velocity analysis can be addressed with the familiar concept of coherence analyses.

The larger number of stacking parameters in the CRS method obviously requires far more computational effort. Furthermore, as two of the stacking parameters, p and v_{CMO}, depend on properties of the unknown reflector in depth rather than on its overburden only, a usual velocity analysis on a sparse grid followed by interpolation is not suitable. Several approaches have been proposed to efficiently perform such a generalized velocity analysis: e. g., Müller (1998, 1999) used a cyclic search strategy in which initial estimates of the parameters are determined one at a time followed by a *local* optimization with all parameters.

Data space vs. model space. In almost all publications on CRS stacking, the three traveltime parameters introduced in equation (2) are expressed as so-called CRS attributes α, R_{N}, and R_{NIP} (see Hubral, 1983, for details). This is, however, only due to a different parameterization of the problem. The above-mentioned attributes were used in the original derivation of the CRS operator. They are related to the depth domain (or model space) and, thus, they are more suitable e. g. for an inversion approach: Duveneck and Hubral (2002) employed the CRS attributes for a tomographic inversion beyond Dix.

In this abstract, we expressed the CRS stacking operator in terms of time domain (or data space) stacking parameters. These are actually searched for in the generalized velocity analysis and they are closely related to the familiar NMO velocity. Therefore, the data space parameters may be easier to understand than their model space counterparts.

The relation between model space and data space parameters is illustrated in Figure 3. In the depth domain, two hypothetical sources generate two sets of hypothetical wavefronts that propagate along the normal ray (blue) with emergence angle α at the surface. An exploding point source at the normal-incidence point NIP generates the NIP wavefronts (red) with radius of

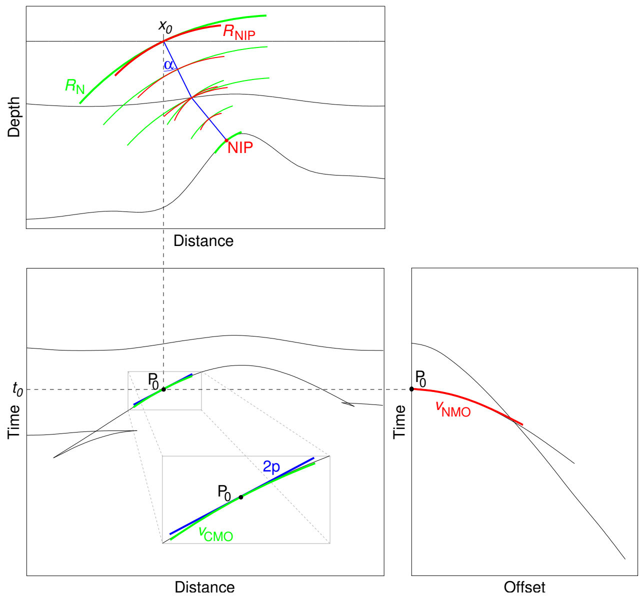

Figure 3: Upper part: sketch of the model space. Two sets of hypothetical wavefronts—NIP wave (red) and normal wave (green)—propagate along the normal ray (blue). At x_0, they can be parameterized by their common emergence angle α and their respective radii of curvature R_{NIP} and R_{N}. Lower part: subsets of the data space. ZO section (left) and CMP gather (right). Point $P_0(x_0,t_0)$ is the location of an event associated with the normal ray shown in the upper part. In this domain, the CRS stacking parameters are given by the curvature of the CMP event (red, v_{NMO}) and the slope (blue, $2p$) and curvature (green, v_{CMO}) of the ZO event.

curvature R_{NIP} at the surface and an exploding reflector experiment generates the normal wavefronts (green) with radius of curvature R_{N} at the surface. The parameters in the different domains are coupled by the near-surface velocity v_0 in the vicinity of the emergence location of the normal ray. Their explicit relationships are $p = \sin\alpha/v_0$, $v^2_{\mathrm{NMO}} = 2v_0 R_{\mathrm{NIP}}/t_0 \cos^2\alpha$, and $v^2_{\mathrm{CMO}} = v_0 R_{\mathrm{N}}/2t_0 \cos^2\alpha$.

Conclusions. We discussed the CRS stack method as a generalization of and alternative to the well-known CMP-based stacking velocity analysis and stack. Both concepts rely on the continuity of reflectors and, thus, on the same model assumptions. Although the CRS stack method increases the complexity of the imaging problem by incorporating neighboring CMP gathers, the idea is to make better use of the data redundancy and to provide additional useful stacking parameters that include and complement stacking velocity.

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