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# Preface

This document contains the MPEG CE Methodology for Haptics. It is intended to be issued as a public document accompanying the Call for Proposals on the Coded Representation of Haptics – Phase 1 [N0070].

The main points of the CE methodology for haptics are:

* The CE Cross-Check phase has additional guidelines (Annex D) that are intended to make the CE acceptance process more predictable and hence less controversial.
* The CE Integration phase requires that additional encoder-related information be supplied by the CE proponent: 1) “signal-path” processing be supplied as full source code; 2) “stubs” be defined that indicate proprietary processing; 3) Instructive text and/or exemplary source code be supplied that explains the processing that occurs in the proprietary “stubs.” It is hoped that the resulting RefSoft Encoder source code would be a greater aid in helping interested parties build their own Reference Quality Encoder.

# Scope

This document describes the core experiment procedures for the MPEG Haptics work. The recommendations in this document are based on the MPEG Audio CE process documents (N1375, N1504, N1748, N5722, N7140, N10664, and N13413), as there has been no previous CE work done on haptics within MPEG.

**Definitions**

The following definitions apply to this document:

* **Working Draft** (WD)refers to the textual description of the technology under development. Note that in the final phases of the standardization process the text is referred to as CD, DIS, FDIS and IS.
* **Reference Software** (RefSoft) refers to an implementation in ANSI C/C++ source code of the technology specified in the text. This includes both the Reference Software Encoder (RefSoft Encoder) that produces conformant bitstreams and the conformant Reference Software Decoder (RefSoft Decoder).
* **Reference Model** (RM) refers to the technology under development, which is expressed in both the WD and the RefSoft. Any addition or change to the RM implies an addition or change to both the WD and the RefSoft.
* **Reference Quality Encoder** (RQE) refers to the best-known encoder implementation, which is typically a proprietary proponent encoder.
* **ANSI C/C++ source code** refers to ANSI C++ source code or ANSI C source code with C++ compatible header files.

**Introduction**

Experiments shall not affect more modules in the RM than necessary. If there is doubt whether this is the case, the MPEG WG 2 may request a more detailed check as a means to understand the effect of smaller-scale changes.

A core experiment always starts at one MPEG meeting with the submission of a proposal and the naming of the parties doing independent coding and/or volunteering to do part of the evaluation. It can span the time between more than one MPEG meetings.

The MPEG process for developing standards is documented in [N6877]. New MPEG delegates are urged to review this document.

# The Core Experiment process

To include a new tool or algorithm into the MPEG Haptics RM, the following three steps are necessary. Only after the completion of all three does a new tool becomes part of the RM. The three steps are:

1. Proposal

2. Check

3. Integration

### 1 Proposal

In the proposal stage, an internal verification and evaluation must be done by the proponent(s). It is assumed that the proponent already has code implementing the proposed new tool or changed tool within the RefSoft.

A proposal must be submitted as an MPEG contribution document and must contain:

* A one page “executive summary”
* Information as to whether the new tool is planned to be an addition to the RM or if it is planned to replace a tool in the RM.
* A technical description which is accurate enough that the main function can be duplicated by someone skilled in the art (this does not mean bit-identical replication of results).
* The WD changes (bitstream syntax and semantics and a description of the decoding process) which are necessary to incorporate the proposed technology.
* A complexity evaluation giving estimates of ROM, RAM, and signal processing functions (e.g., weighted MOPS) necessary to implement the tool. See Annex B.
* Evidence for the merit of the new tool (for example subjective test results), see Annex B and C.

A CE shall be conducted using the Reference Quality Encoder (RQE) and the Reference Software decoder (RefSoft Decoder). If the RQE is a proprietary encoder, the owner of that encoder shall work with the CE proponent to define suitable APIs to support the CE and then work with the CE proponent to encode the CE test items.

Manual tuning (i.e., per-item tuning) of the encoder used in the process of preparation of test material is explicitly prohibited.

If there is a conflict between proposals in which the tool of one CE affects the tool of another CE (i.e., a first CE changes the RM environment in which the second CE must be evaluated), the CE whose proponent was first to present a complete proposal shall have precedence.

If there is a conflict between proposals in which both CEs target the same functionality (i.e., two versions of the same tool), proponents should attempt to forge a unified proposal. If this is not possible, a more rigorous evaluation must be done. In this case, objective parameters (delay, complexity) should be part of the evaluation.

### 2 Check

The check phase ensures that the proposal is implemented, tested, and reviewed by at least one company in addition to what was provided by the proponent in the Proposal phase. The check-phase information must be submitted as an MPEG contribution document.

**Verify Implementation**

This is a check on the software implementation of the proposal. At least one check by an independent company must be performed. (It is assumed that one check is provided by the proponent in the Proposal phase.) It is acceptable if this is using the same software implementation, however an independent implementation is preferred. At the Check phase, proponent core experiment decoder software (i.e., extensions to the RefSoft Decoder) can be made available as an executable or as object modules with a suitable interface to the RefSoft Decoder. However, the successful completion of the core experiment requires that source code be delivered and integrated into the RefSoft, as described in Section 3 of this document.

**Verify Performance**

Assessment of performance (e.g., subjective tests) should be done by at least one lab. (It is assumed that the proponent provided one assessment of performance in the Proposal phase.) The details of such tests are described in [BS.1534]. See Annex B for details concerning conducting subjective tests and measuring complexity and Annex C for details concerning statistical calculations. The requirement for an additional subjective test is dropped if an independent commercial test lab conducted the Proposal phase evaluation.

The result of the check phase is a report on the technique, its merits, and associated test results. The result should take into account the improvement (if any), theoretical considerations, and the complexity of the feature.

In the case that a subjective test is part of the check phase, material used in the subjective test must be made available at a reasonable interval (to be determined at each MPEG meeting) prior to the MPEG meeting where the results are presented, such that other members of MPEG members have the opportunity to do informal evaluation.

If the result of the check phase is not consistent amongst the companies doing the review, a report should present the different results, and the MPEG WG 2 may request an additional check.

The acceptance of a core experiment is based on the guidelines described in Annex D.

### 3 Integration

After the success of a core experiment, encoder and decoder components for the new tool must be integrated into the WD and the RefSoft. Source code shall carry the appropriate ISO copyright notice.

After integration, it is expected that the RefSoft Decoder shall be able to decode the CE bitstreams to produce the bit-exact waveforms used in the CE evaluation. In the case non-normative decoder components have been used, appropriate “stubs” shall be supplied, similar to what is defined below for the RefSoft Encoder. The proponent must supply sufficient support, as educational text and/or exemplary source code to assist others to implement the tool in their decoder.

For the RefSoft Encoder, the proponent must provide:

* Additional modules or modifications to existing modules, as ANSI C or C++ source code, that implement “signal flow” portions of the CE technology. It is understood that these source code modules would not reveal any undisclosed proponent “know-how.” For example, they might be exact mirrors of what is found in modules of the RefSoft Decoder, such as an encoder forward transform or analysis filterbank that would correspond to a RefSoft Decoder inverse transform or synthesis filterbank.
* Source code function “stubs” that would contain proprietary “know-how,” for example a psychoacoustic model. The stubs do not have any functionality and need not even have a complete set of function arguments (as the required set of function arguments may itself be a component of proponent “know-how”).
* Sufficient support, as educational text and/or exemplary source code to assist others to implement the tool in their encoder. It would be best if this discussion and/or exemplary source code is in the context of the “stubs” in the RefSoft Encoder and in this respect actually describes the processing necessary in the “stub” routines. This should become part of the encoder informative section in the WD.

These three components for the RefSoft encoder must be accepted by the consensus of the MPEG WG 2. If what is provided by the CE proponent is judged to not be acceptable, the MPEG WG 2 must draft a workplan that identifies the additional steps the CE proponent must take to gain acceptance by the group.

Satisfactory completion of the integration phase concludes the Core Experiment. This integration is typically concluded in the AHG period following the MPEG meeting at which the check phase was successfully completed.

**References**

[N6877] MPEG 101, issued at 71st MPEG meeting.

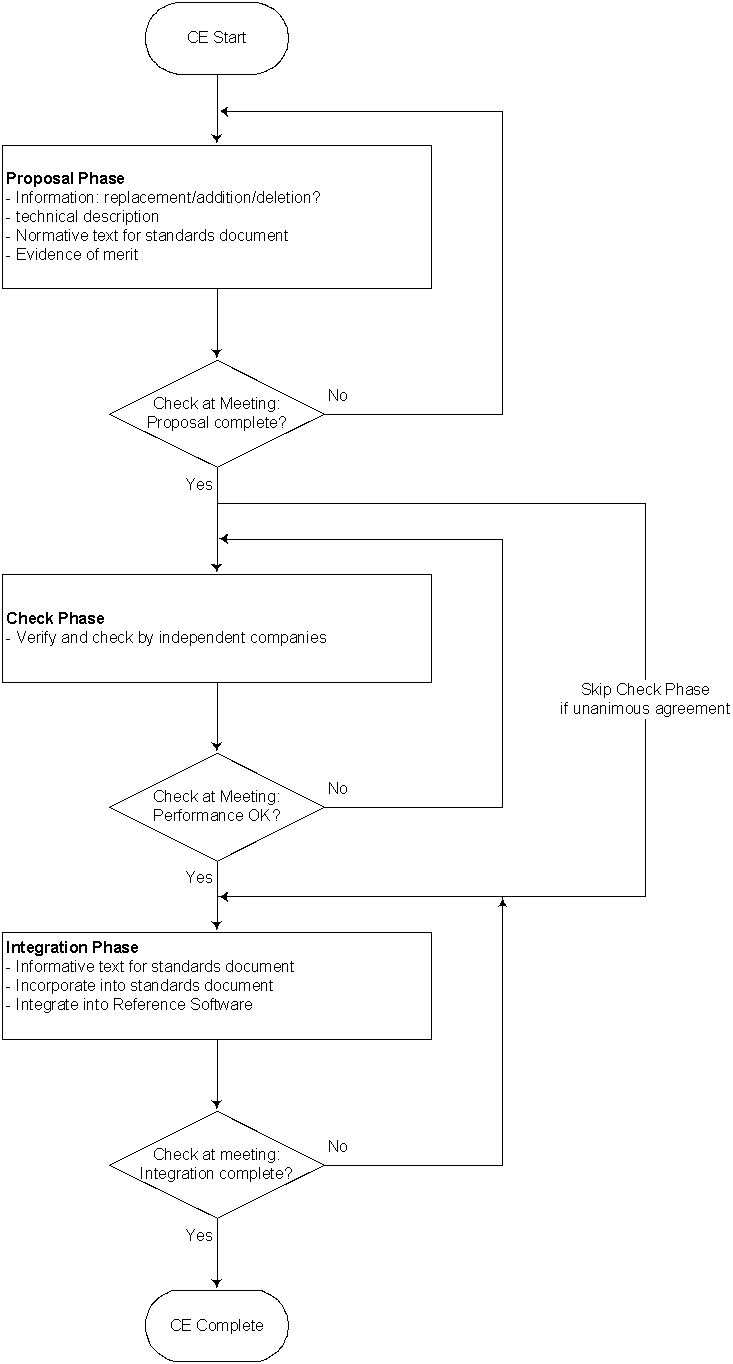
[BS.1116] ITU-R Recommendation BS. 1116-1, “Methods for the subjective assessment of small impairments in audio systems including multichannel sound systems,” Geneva, Switzerland, 1994-1997.”

[BS.1534] ITU-R Recommendation BS.1534-3, “Method for the subjective assessment of intermediate quality level of coding systems: MUlti-Stimulus test with Hidden Reference and Anchor (MUSHRA),” Geneva, Switzerland, 2015.”

[BS.1284] ITU-R Recommendation BS.1284-1, “General methods for the subjective assessment of sound quality,” Geneva, Switzerland, 1997-2003.

[N0070] WG02 N0070 Call for Proposals on the Coded Representation of Haptics – Phase 1.

# Annex A: Core Experiment Process Flow Chart



**Annex B: Performance Measurement Procedures**

1. **Procedure for subjective quality tests**

* A minimum of 8 test subjects is required at each test site.
* The test material to be used in the Core Experiment process is identified in Annex 5 of the Call for Proposals on the Coded Representation of Haptics – Phase 1.
* If tools evaluated with the CE process are applicable to a specific type of haptic material, the regular set of items can be restricted to a subset, or new material can be added. The MPEG WG 2 must agree to this on a per-CE basis.
* Test subjects must participate in a training phase prior to the actual test so that they are familiar with
  + The original (unprocessed) items.
  + Processed items representative of the range of impairments found in the actual test.
* Presentation should be done via computer control with near-instantaneous switching between test stimuli.
* Results should be presented for each item (averaged over all test subjects) and per systems (averaged over all test subjects and all items). In addition, results may be presented for pooling over all test sites and all operating points. In any case, subjective test results from all test sites should be considered.
* The CE technology may be assessed using differential scores and a single-sided t-test (see Annex C) if there is only a single CE configuration to be compared against a single Reference configuration. Single-sided test results should be done for data pooled over all test subjects and all test items.
* Subjective test methodologies can be
  + BS.1116 [BS.1116] (recommended for technology with small impairments).
  + MUSHRA [BS.1534] (recommended for technology with moderate impairments).
  + Comparative [BS.1284] (recommended only as a source of additional information)
* If BS.1116 then
  + Score data should be analyzed as “diff scores” which are differences in scores (RM+CE – Original) on a per-test-subject-response basis.
* If MUSHRA then
  + Tests must include a hidden reference and an open reference signal.
  + In order to enhance the significance of the subjective test results, it is suggested that post-screening of the test subjects be done as follows: All data associated with subjects satisfying the following criterion are removed from the corresponding test.
    - The subject’s score for the hidden reference stimuli was below 90.
  + Score data should be analyzed and presented as both absolute scores and diff-scores relative to the RM system (i.e. (RM+CE) – RM). Differences are to be computed on a per-test-subject-response basis.
* If Comparative then
  + It is assumed that score data permits calculation of mean and 95% confidence intervals as in the BS.1116 and MUSHRA methodologies.

1. **Procedure for complexity reduction or functionality addition with possible quality degradation**

* Use the same procedure for subjective quality assessment as in Section 1, above.
* Measure CE reduction in computational complexity using weighted MOPS (e.g., 1 instruction per MAC, 10 instructions per square root or log operation). Report:
  + Complexity of CE technology
  + Total complexity of RM+CE
  + Ratio of (RM+CE)/RM complexity (i.e., percent change in decoder complexity when incorporating CE).
* Measure CE reduction in table size (i.e., ROM size) in Kbytes or Mbytes. Report:
  + Complexity of CE technology
  + Total complexity of RM+CE
  + Ratio of (RM+CE)/RM complexity (i.e., percent change in decoder complexity when incorporating CE).
* The proponent can measure functionality in any manner judged most appropriate.

1. **Procedure for enhanced functionality or increased compression producing bit-identical output**

* Report the functionality and the complexity as in Section 2, above.
* At least one additional independent check on functionality or compression and identical reconstruction. (It is assumed that the proponent provided one such assessment in the Proposal phase.)

# Annex C: Statistical Calculations

## Confidence Interval on the Mean Score

A 95% confidence interval on the mean of a statistic is calculated as

,

where is the Student t statistic with single-sided tail probability of  and *n-1* degrees of freedom,

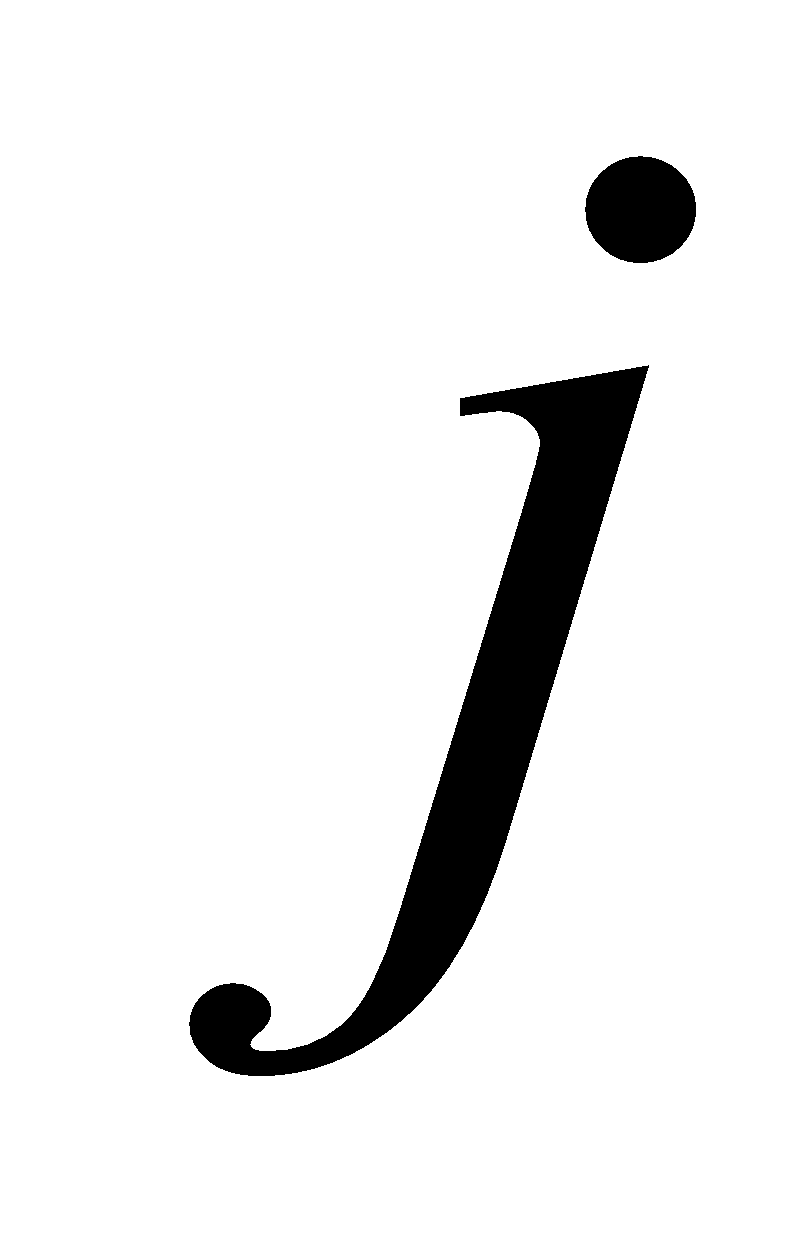
*μ* is the average:

,

and *σ* is the standard deviation:

,

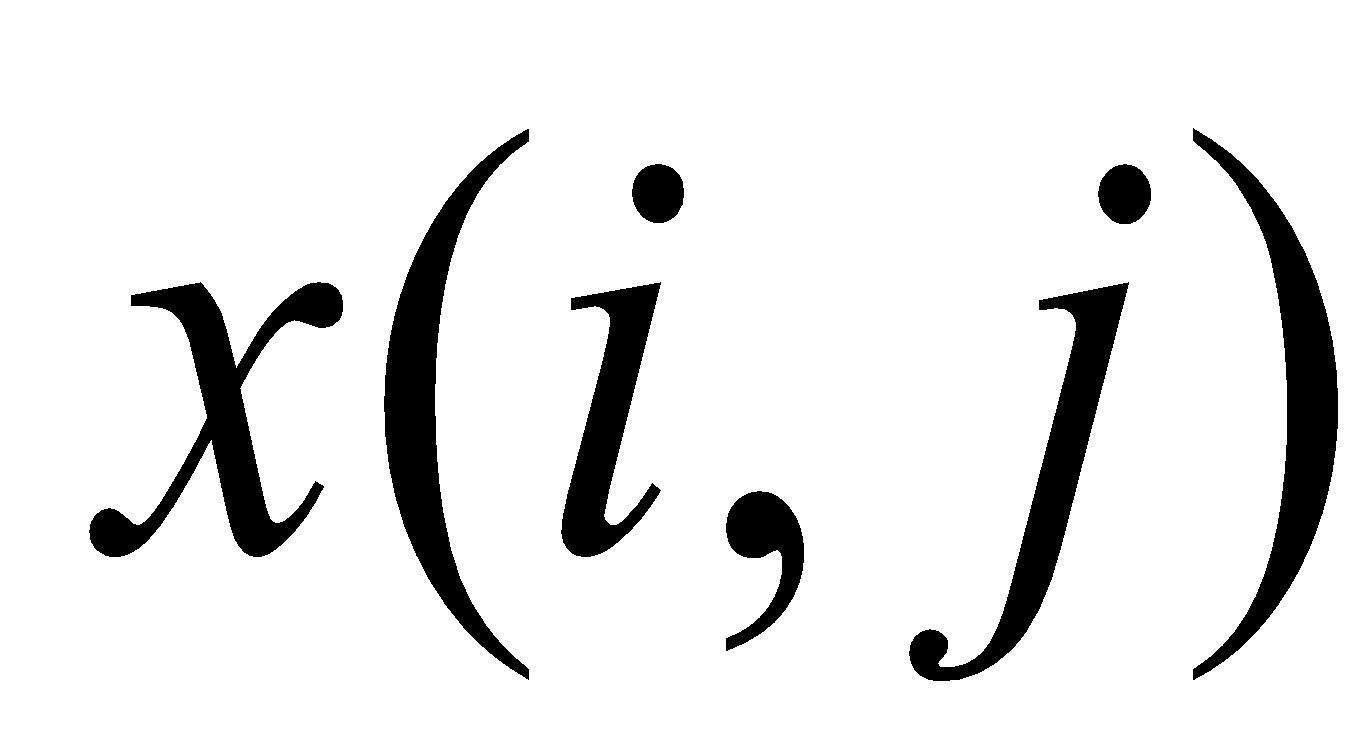
where *N* is the sample size (e.g., number of test subjects) and *xk* denotes the individual sample values (e.g., individual test subject score).

Note that index *k* in xk enumerates the number of test subjects and test items and is appropriate for estimates that are pooled across all test subjects and all test items. If estimates per test item are desired, xk could be expressed as where is the subject (i.e., test subject) index and  is the item index.



Note further that  converges to 1.96 as n goes to infinity, so that for large n, the t-distribution converges to the Normal distribution. It is within 2% of 1.96 for n > 60.

## Confidence Interval on the Mean of Diff-Scores

If it is desired to analyze the difference between scores on a per-test-subject-response basis (e.g., between a system under test and the reference system), then statistic  is replaced by



where

are the scores for the reference system, and



are the scores for the system under test



A 95% confidence interval on the mean of the difference statistic is calculated as indicated above.

## Single-Sided Test

A single sided test on the difference between scores can be applied to determine whether the system under test is better than the reference system, in a statistical sense. This tests whether the assumption that there is no difference between the reference system and the system under test (the so-called Null hypothesis) is rejected. A criterion is set such that there is an error of 5% (Type I error) that we falsely rejected this assumption. Given a 5% Type I error probability, the critical value is  times the standard deviation for the t-distribution, where converges to 1.64 for large n.

The testing procedure is as follows:

- calculate the critical value 

- test whether



There are only two possible outcomes:

**Case 1**: . The Null Hypothesis is rejected, and it is concluded that the system under test is better than the reference at the one-sided 95% level of significance.



**Case 2**: . The Null Hypothesis is not rejected so that we cannot conclude that the system under test is better than the reference.



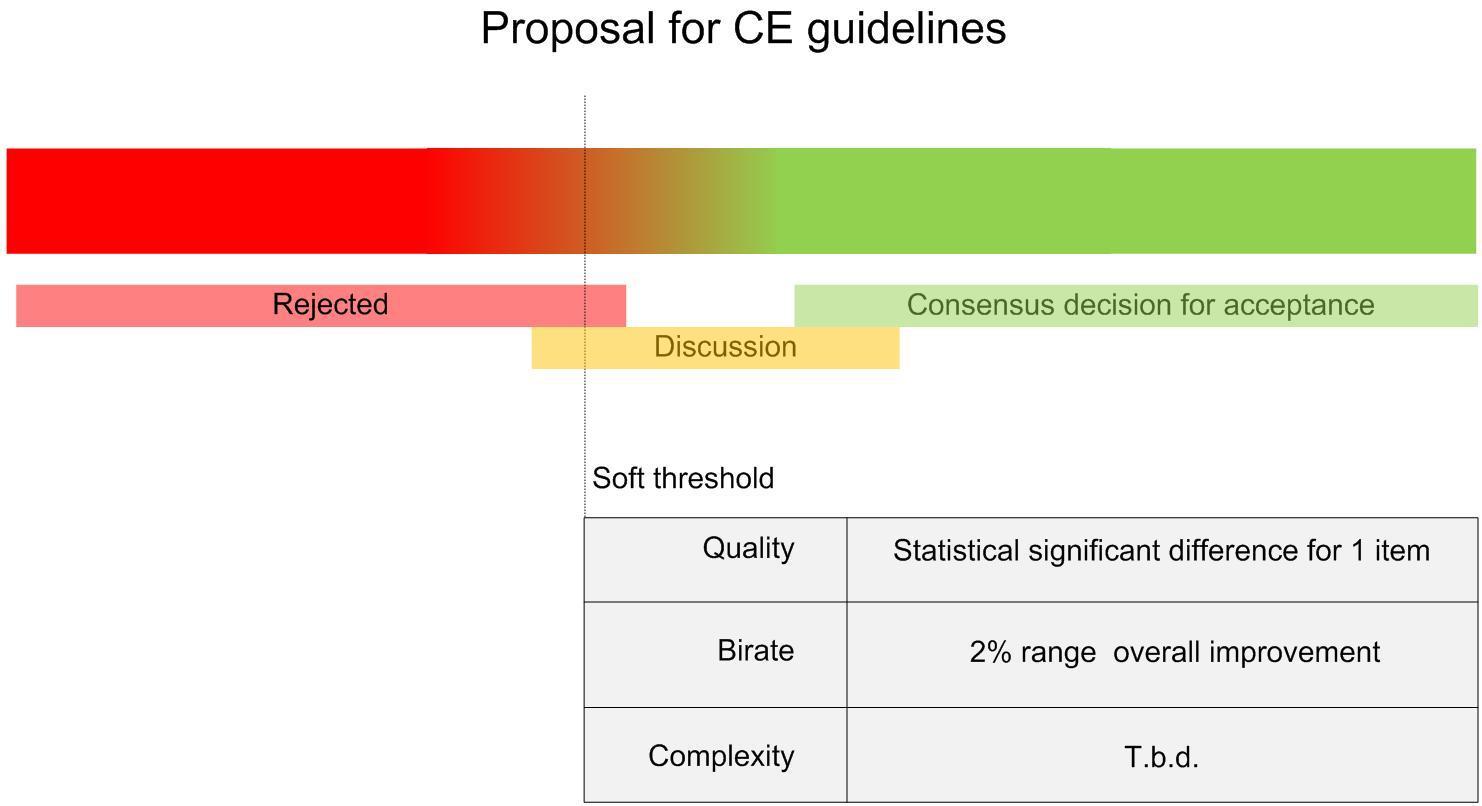
## Student t and Normal distributions

The statistical calculations above are given for both Student t and Normal distributions. However, [Student's *t* distribution](http://en.wikipedia.org/wiki/Student%27s_t-distribution) must be used to calculate confidence intervals when the number of observations is small (i.e. n < 60). This would be appropriate when computing per-item confidence intervals where the number of test subjects is small (e.g., 8). In the case that the Normal distribution is used instead of Student's *t* distribution to calculate confidence intervals, this must be clearly stated when test results are reported.

# Annex D: Evaluation of Performance Information

As part of the check phase approval process, the MPEG WG 2 will classify CEs into one of the following two categories and apply a separate process for each of these categories:

* **Sensible engineering**  
  Proposals in this category typically do not provide any gain in terms of quality, bitrate or complexity. The objective of such proposals is to resolve bugs and inconsistencies in text and reference SW or provide better alignment with other modules. Proposals in this category should be discussed amongst the experts in the MPEG WG 2 after which a decision based on technical arguments is made on whether to adopt, reject or possibly reconsider the proposal at a future MPEG meeting.
* **Performance gain in quality, bitrate or complexity**  
  Proposals in this category target an improvement in quality, reduction in bitrate or reduction in complexity. Figure 1 and the following discussion give guidance as to how to proceed with this type of proposal.



**Figure 1 – Illustration of CE “Soft Threshold” concept.**

As part of the CE requirements, each CE needs to provide clear information on its improvement in terms of subjective test results, overall bitrate reduction and/or overall complexity reduction. These data will rank the proposals with respect to the soft threshold that is illustrated in Figure 1. The soft threshold for quality, bitrate and complexity is given in the following table:

|  |  |
| --- | --- |
| **Parameter** | **Soft Threshold** |
| Quality | Statistically better for 1 item, none worse |
| Bitrate | 2% overall improvement |
| Complexity | 5% overall improvement |

A discussion of these thresholds follows:

* **Quality**  
  Statistically better for at least 1 item and no item worse with respect to the current WD status. This may be determined using absolute subjective or differential subjective results using two-sided confidence intervals. “Better for at least 1 item” means that there is at least one item for which the confidence interval for the (RM+CE) mean score is higher than and does not overlap with the confidence interval for the corresponding RM mean score. “No item worse” means that there is no item for which the confidence interval for the (RM+CE) mean score is lower than and does not overlap with the confidence interval for the corresponding RM mean score.

The notion of Just Noticeable Difference (JND) for a given subjective test methodology and test scale should be discussed and taken into consideration. CE technology whose subjective improvement does not surpass the JND clearly does not provide a perceptible difference.

* **Bitrate**  
  Although proposals targeting only bitrate reduction typically accomplish this without any change in decoded output (at least when issues of bit budget and bit allocation are ignored), in the end the objective is that bitrate savings give rise to an increase in perceived touch quality. With this in mind, it is observed that differences in bitrate below 2%-5% are too low to result in a noticeable difference in a subjective test. It is also recognized that a noticeable gain in quality could of course become apparent by combining different proposals that do not show a difference in quality when tested individually. It is however more likely that a noticeable gain in subjective quality can only be achieved when combining proposals that show a gain in bit-rate in the order of 2%-5%. Proposals with a gain well below 1% will in the end likely have no contribution to the quality improvement. For this reason, the soft threshold is set to 2% for proposals targeting bitrate reduction.
* **Complexity**  
  In certain application scenarios, issues of complexity are of primary concern for the decoder, and typically much less of a concern for the encoder. Complexity enters the discussion in two ways. Either a proposal has as its main merit the reduction of complexity, or a proposal has another merit of e.g., quality improvements at a cost of a certain additional complexity. Either way, the complexity, be it computational complexity or RAM/ROM requirements, needs to be presented in relation to the entire complexity of the decoder system. Furthermore, it is imperative that the complexity measurements are done in a scientific and rigorous manner e.g., by counting WMOPS, KB of table size, etc. With this in mind, measurements of decoder execution time on a specific platform cannot be considered to constitute sufficient evidence of any complexity increase or reduction. It is further noted that providing the complexity numbers in relation to functionally comparable technology in the marketplace would allow experts in the group to better judge the proposal. A soft threshold is set at 5% overall reduction in complexity.

For proposals with a merit below the soft threshold:

The larger the distance below the soft threshold, the less likely it should be to gain the support of MPEG experts, subject to consideration of all other evidence of merit.

For proposals with a merit that is above the soft threshold:

The larger the distance above the soft threshold, the more likely it should be to gain the support of MPEG experts, subject to consideration of all other evidence of merit.