A Spectral Based Colour Gamut for Real Objects*

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Outlines

1. Why do we need a colour gamut for real objects
2. What are the available colour gamuts
3. Why do we need a new colour gamut
4. Why do we need a colour gamut in terms of reflectance
5. How the spectral gamut is developed
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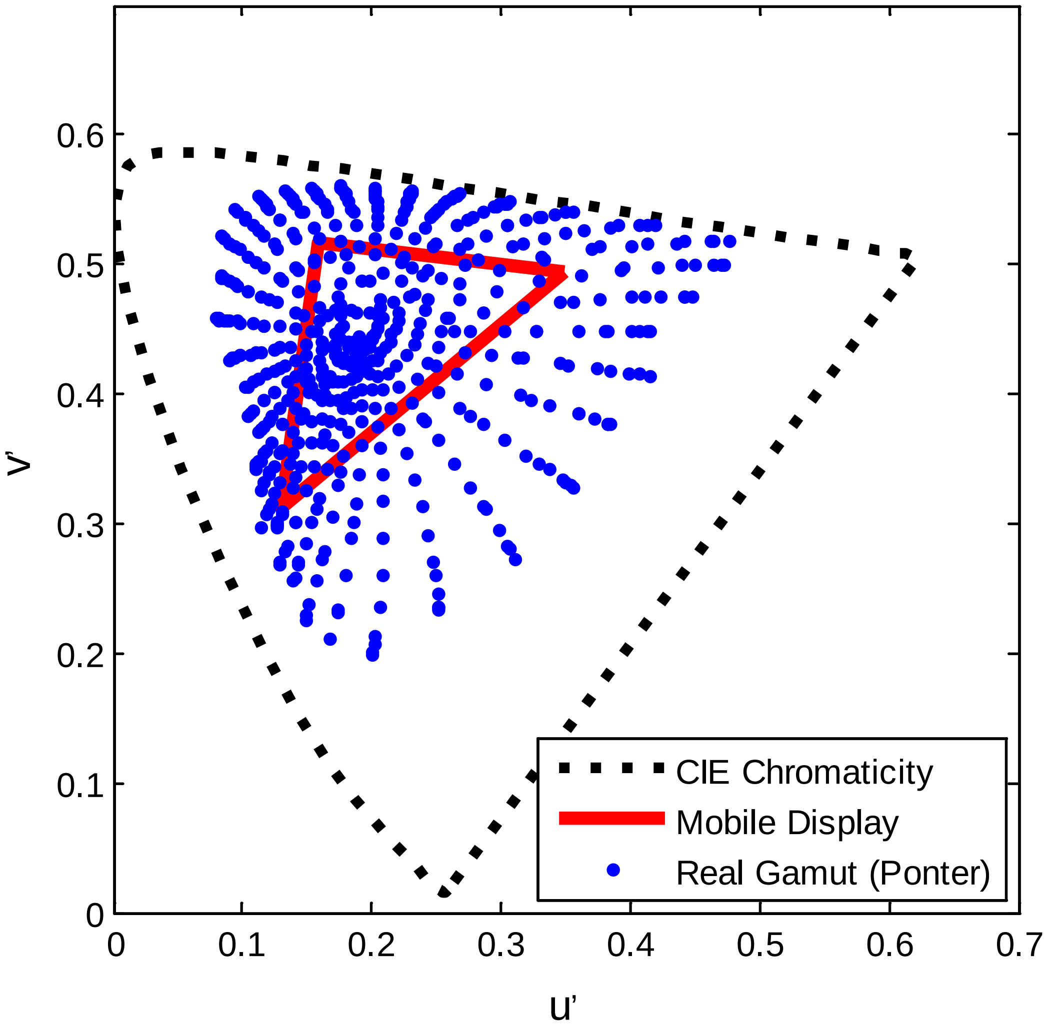
Why do we need a colour gamut for real objects?

Industries such as colour photography, colour printing and colour television are concerned with the reproduction of real world colours, including a small portion of natural and a large portion of real (man-made) samples.

The colour management workflow that leads to successful cross-media colour reproduction can be enhanced by knowledge of the colour gamuts of the specific image reproduction devices and real surface colours.

It is also desirable to be able to compare the colour gamuts of different image reproduction devices and media if we know the colour gamut of real objects.

Why do we need a colour gamut for real objects?



What are the available 3D colour gamuts?

Pointer's Gamut (1980)

Gamut defined in terms of LCh CIELAB coordinates under C/2° .

L* was sampled at 15,20, …, 90 at 5 units interval

h was sampled at 0° , 10° , …,350° at 10° interval

Pointer's Gamut under C/2°

L* (16 levels)

	15	20	25	...	80	85	90
0°	10	30	43	...	30	19	8
10°	15	30	45	...	30	18	7
20°	14	34	49	...	30	19	9
⋮	⋮	⋮	⋮	C*	⋮	⋮	⋮
330°	20	50	72	...	27	18	9
340°	26	49	63	...	28	16	4
350°	15	37	52	...	30	17	6

h

36 levels

576 (36*16) C* values

What are the available 3D colour gamuts?

ISO Gamut of Surface Colours (ISOGSC, 1998)

Gamut defined in terms of L*C*h CIELAB coordinates under D50/2° .

L* was sampled at 5,10, …, 95 at 5 units interval

h was sampled at 0° , 10° , …,350° at 10° interval

This set of gamut was derived based on Pointer's data plus 1025 Pantone data, a series of new data measured from printed samples, and ISO SOCS (standard object colour spectra) data.

What are the available 3D colour gamuts?

Hewlett Packard (HP) Printer Gamut

Gamut defined in terms of L*C*h CIELAB coordinates under D50/2° .

L* was sampled at 10, 20, …, 90 at 10 units interval

h was sampled at 0° , 22.5° , …,337.5° at 22.5° interval

This set of gamut was developed by experts at HP based on a large number of printed colour samples during their product development. Coordinates were calculated relative to the media white with TSV given by:

$$(X_{RW},\ Y_{RW},\ Z_{RW}) = (85.8138,\ 89.0,\ 73.4161)$$

What are the available 3D colour gamuts?

The PhotoRGB Gamut

Gamut defined in terms of L*C*h CIELAB coordinates under D50/2° .

L* was sampled at 10, 20, …, 90 at 10 units interval

h was sampled at 0° , 20° , …,340° at 20° interval

The gamut was defined by colour imaging experts involved with the reproduction of digital photographs in Germany. Coordinates were calculated relative to the media white with TSV given by:

$$(X_{\mathrm{RW}},\ Y_{\mathrm{RW}},\ Z_{\mathrm{RW}}) = (85.8138,\ 89.0,\ 73.4161)$$

What are the available 3D colour gamuts?

ISO Reference Colour Gamut (ISORCG, 2007)

Gamut defined in terms of L*C*h CIELAB coordinates under D50/2° .

L* was sampled at 5,10, …, 95 at 5 units interval

h was sampled at 0° , 10° , …,350° at 10° interval

This gamut was adopted as the Perceptual Reference Medium Gamut for ICC profiles. Coordinates were calculated relative to the media white with TSV given by:

$$(X_{\mathrm{RW}},\ Y_{\mathrm{RW}},\ Z_{\mathrm{RW}}) = (85.8138,\ 89.0,\ 73.4161)$$

What are the available 3D colour gamuts?

Gamut	Sampling points	**LOI**	Ill.	**AORC**
MP (Pointer)	h: 0, 10, …, 350	10°	C	Absolute
	L*: 15,20,…90	5		
ISOGSC	h: 0, 10 ,…, 350	10°	D50	Unknown
	L*: 5,10,…,95	5		
HP (Printer)	h: 0, 22.5, …, 337.5	22.5°	D50	Relative
	L: 10,20,…,90	10		
RGB	h: 0, 20, …, 340	20°	D50	Relative
	L*: 10,20,…,90	10		
ISORCG	h: 0, 10, …, 350	10°	D50	Relative
	L*: 5,10,…,95	5		

LOI: length of interval; **AORC**: absolute or relative coloremitry

What are the available 3D colour gamuts?

Relative colorimetric data can be obtained using following steps:

1) Measure or compute the tristimulus values (TSV) of the media white, denoted by $(X_{\mathrm{RW}}, Y_{\mathrm{RW}}, Z_{\mathrm{RW}})$, using the colorimeter or spectrophotometer and a defined illuminant and standard observer.

2) Compute the scaling factor, $S = \dfrac{100}{Y_{\mathrm{RW}}}$;

3) Compute the TSV (X', Y', Z') using spectral reflectance (r), the spectral power distribution of the considered illuminant and standard observer;

4) Compute the media relative TSV (X, Y, Z) using the formula: $(X, Y, Z) = (X', Y', Z') * S$.

Note that TSV X ', Y ', Z' in step 3 are absolute data.

Why do we need a new colour gamut?

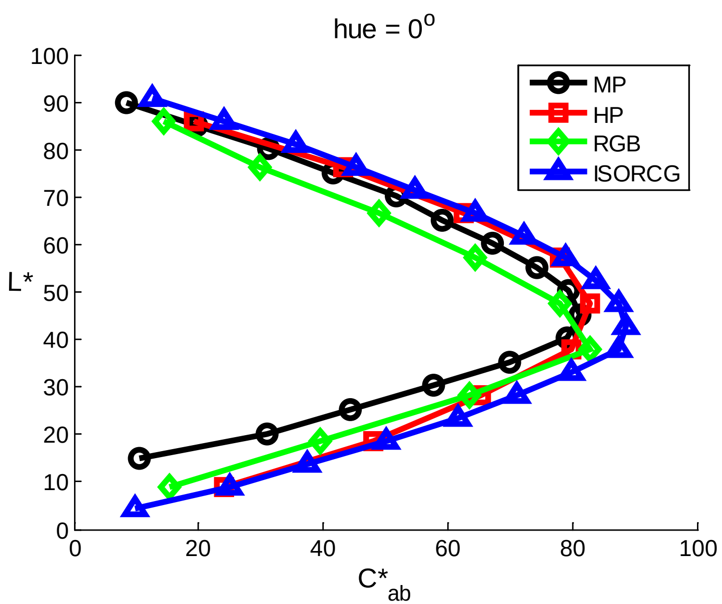
New colour spectral data are available and we can compare the existed colour gamuts together with the new data.

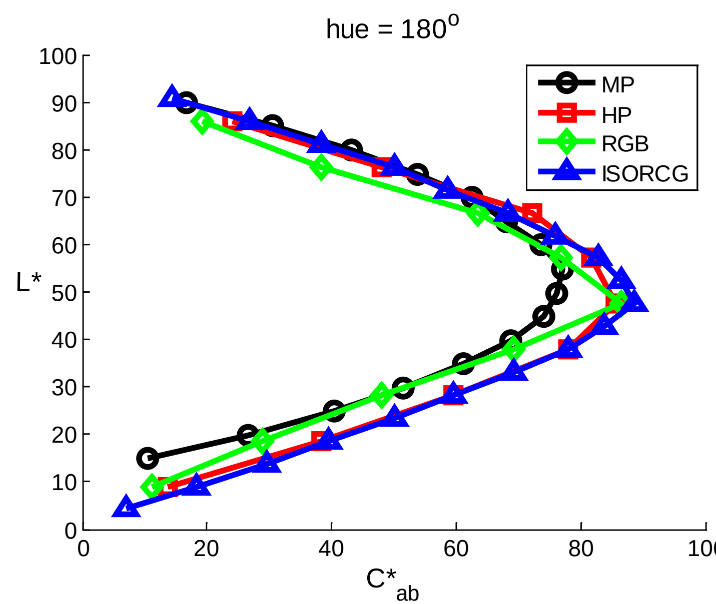
Data set	No. of samples	Surface
Group 1		
Sun Chemical	26784	Ink on paper
Munsell (Glossy version)	1560	Paint
NCS	1749	Paint
DIN	981	Paint
Munsell Limit Colour Cascade	720	Paint
Du Pont Spectra-Master	672	Paint
Group 2		
ISO SOCS(Calibration Data)	136	Colour Patches
ISO SOCS (Skin)	8570	Skin
ISO SOCS(Flowers)	148	Natural
ISO SOCS(Graphics)	30624	CMYK Printed
ISO SOCS(Krinov)	346	Outdoor scenes
ISO SOCS(Leaves)	92	Leaves
ISO SOCS(Paint)	505	Painted Objects
ISO SOCS(Photos)	2304	Colour Patches
ISO SOCS(Printer)	7856	Colour Patch Images
ISO SOCS(Textile)	2832	Textiles
Total	85879	

Why do we need a new colour gamut?

We can compare the four gamuts first. Since they have the same hue planes at h=0º and 180º, they can be compared at the two hue planes as shown below.

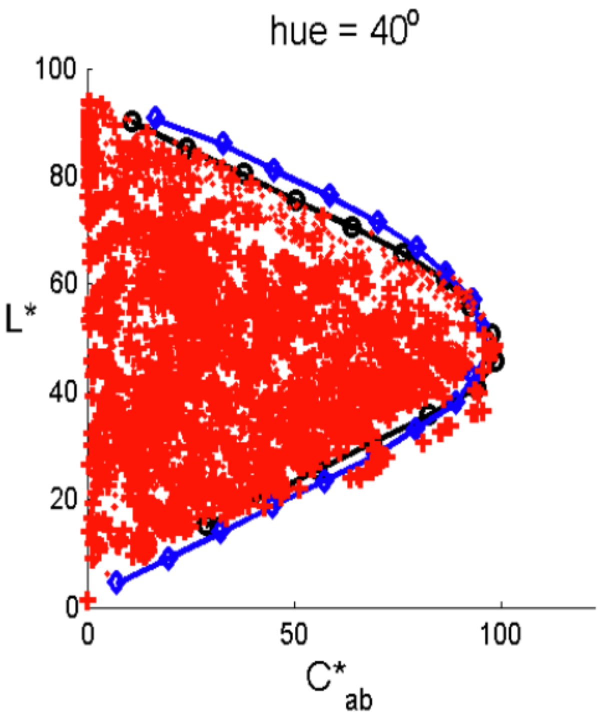
It seems ISORCG is the largest and Pointer gamut is smallest for darker side and the PhotoRGB gamut is the smallest for brighter side.

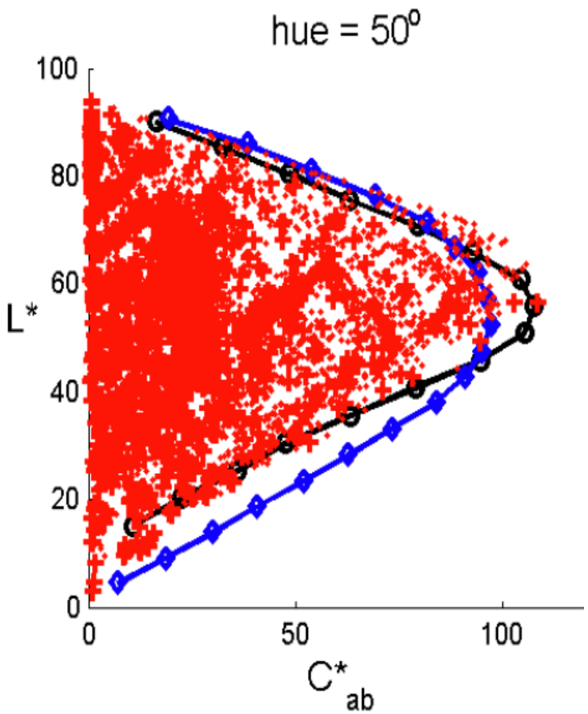




Why do we need a new colour gamut?

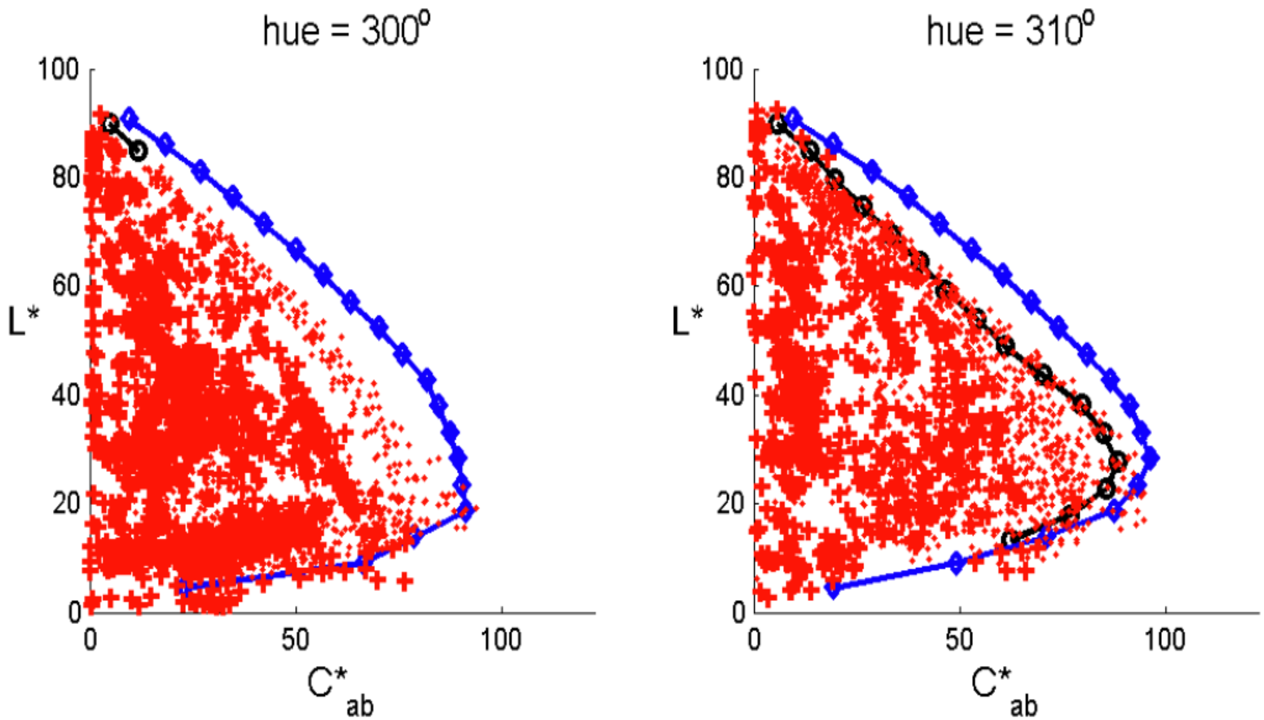
Here Pointer (black curve) and ISORCG (blue curve) gamuts together with real data (read dots and plus) are compared. Generally speaking Pointer gamut is smaller than real data and the ISORCG. However, the two figures show in certain part the Pointer gamut is larger than the ISORCG which is unexpected. Further, some data may be outside the ISORCG as well.





Why do we need a new colour gamut?

It was also found that the ISORCG is larger than necessary since there are gaps between real data and ISORCG. Furthermore, the Pointer gamut has only 2 points left in the hue of 300°, which was caused by the CAT mapping from C to D50 for the comparison.



Why do we need a new colour gamut?

From the comparison we can summarize the problems with the existed gamuts:

1. The Pointer gamut is smaller than the new data in most regions of colour space;
2. the Pointer gamut is smaller than the ISORCG in general. However, it is larger than the ISORCG in certain hue planes, which is unexpected;
3. the ISORCG is larger than the real data in certain parts and is smaller than the real data for certain hue planes.

Thus, neither the Pointer gamut nor the ISORCG gives a good fit to the real data. It can be concluded that there is a need to derive a new gamut which better represents the real surface data

Why do we need a new colour gamut?

Another problem was also fund with the gamut defined in terms of colorimetrical coordinates under a particular illuminant. For example, when comparing the gamuts we have to transform the Pointer gamut from C to D50 using the CAT, which causes new problems such as a) not accurate ; b) colour shifts.

All imply that there is a need to define a reference colour gamut not only in terms of colour coordinates, but also in terms of reflectance functions, which led to the set up of CIE TC1-73 *Real Colour Gamuts* to address this issue. The Terms of Reference of this TC are: To recommend a gamut representative of real (non-fluorescent) surface colours and defined by associated spectral reflectance data.

How the Spectral Gamut Is Developed?

Firstly, a set of gamut is developed in terms of *L**, *C**, and *h* under D50/2° with aiming of

1): representing available data well;

2) smooth and convex in L*C* space;

and 3) boundary smooth in a*b* space as well.

The set of gamut has 36*19=684 points with h sampling from 0° to 350° at 10° intervals and L* sampling at from 5 to 95 at 5 L* unit interval. In addition, there are two common extreme points with L*=97, C*=0, and L*=2.5 and C*=0.

How the Spectral Gamut Is Developed?

Secondly, reflectance functions are generated based on the given colour coordinates X, Y, and Z *via* L^*, C^*, and h.

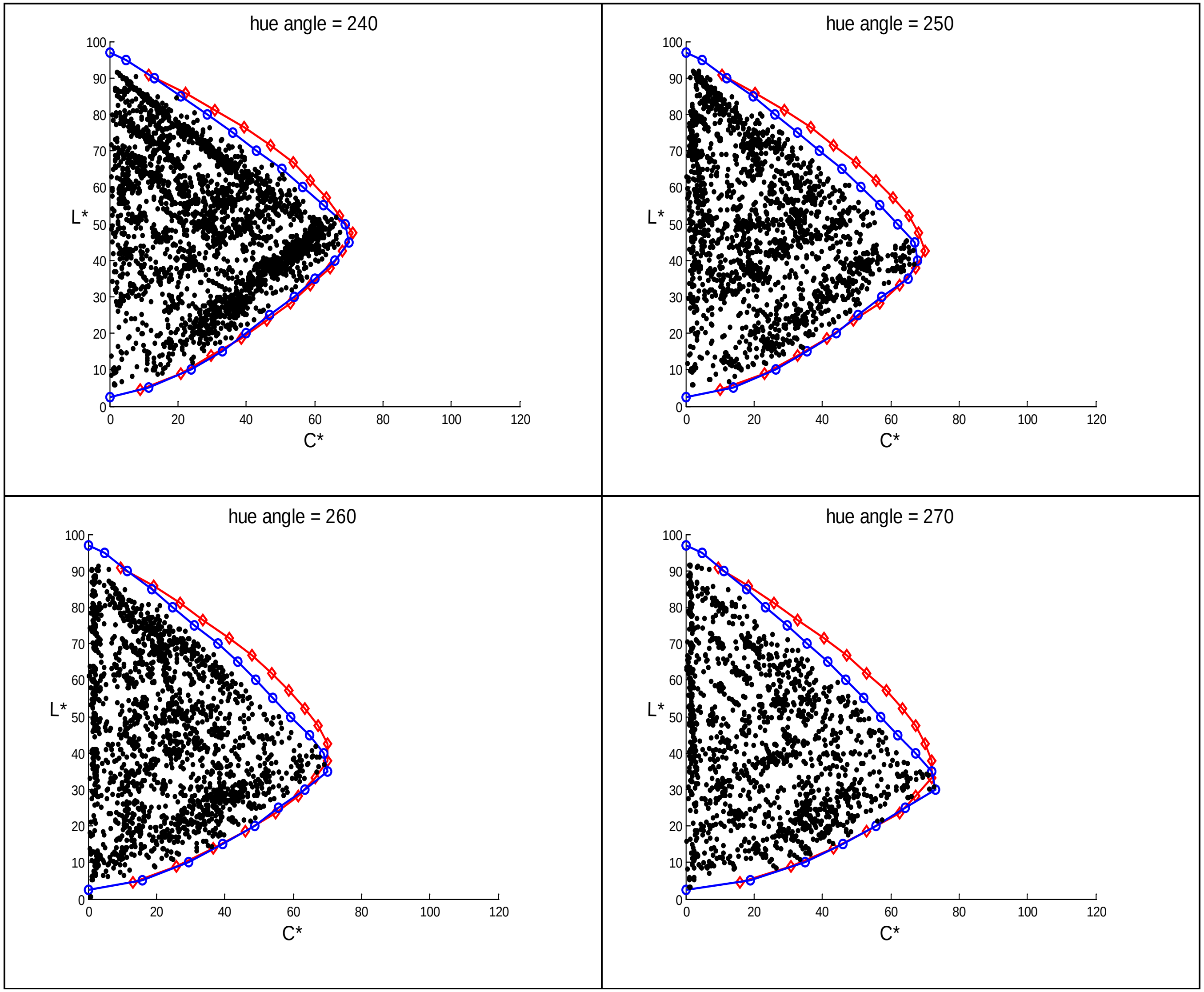
However, the problem is not yet solved satisfactorily. The difficulty is that the number of equations is much less than the number of unknowns. Thus the (inverse) problem is not well defined.

We have to introduce more constraints such as

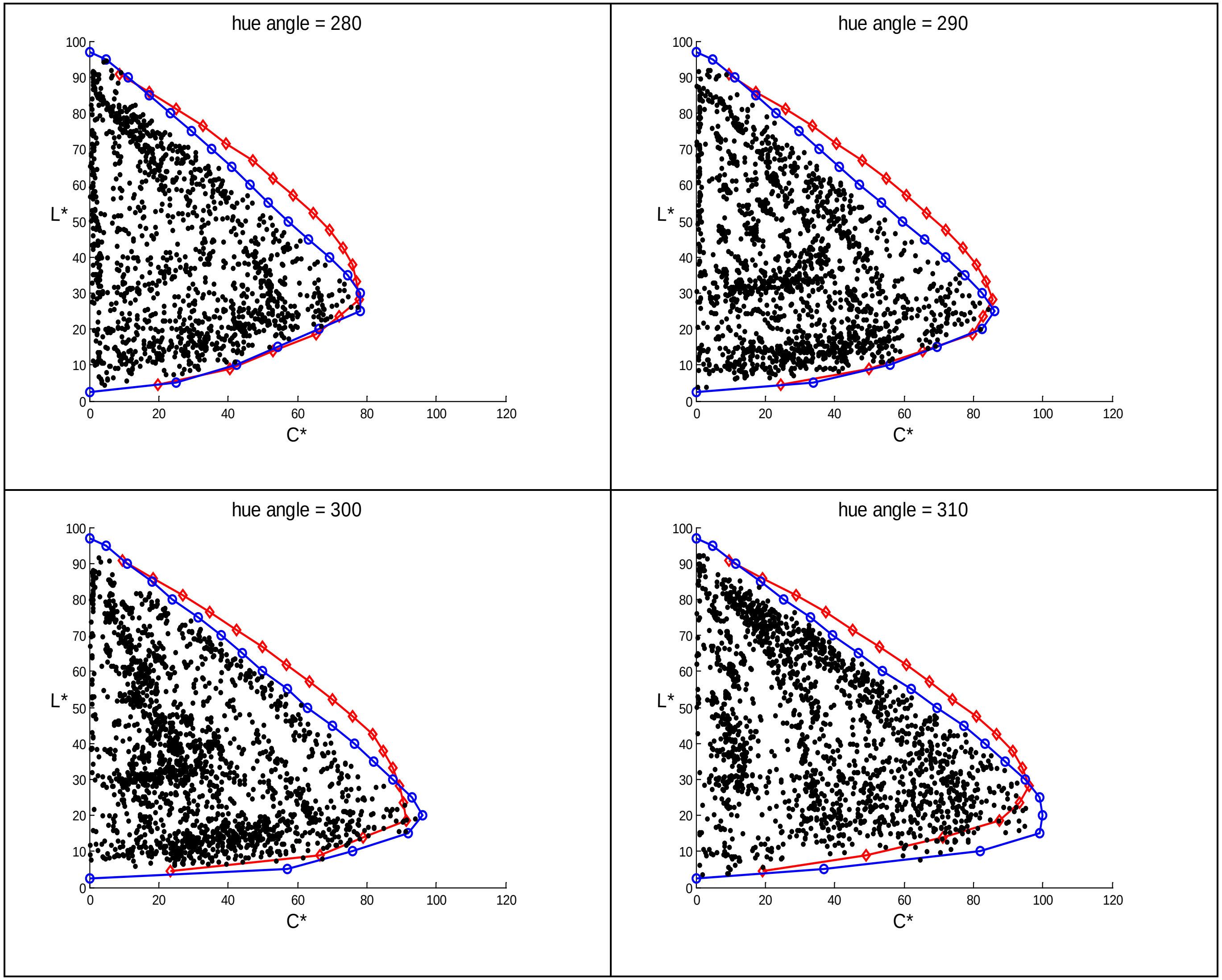
- localised basis vectors,
- smoothest conditions, and
- colour constancy

to reduce the dimensionality of the problem, which leads to a constrained least squares problem.

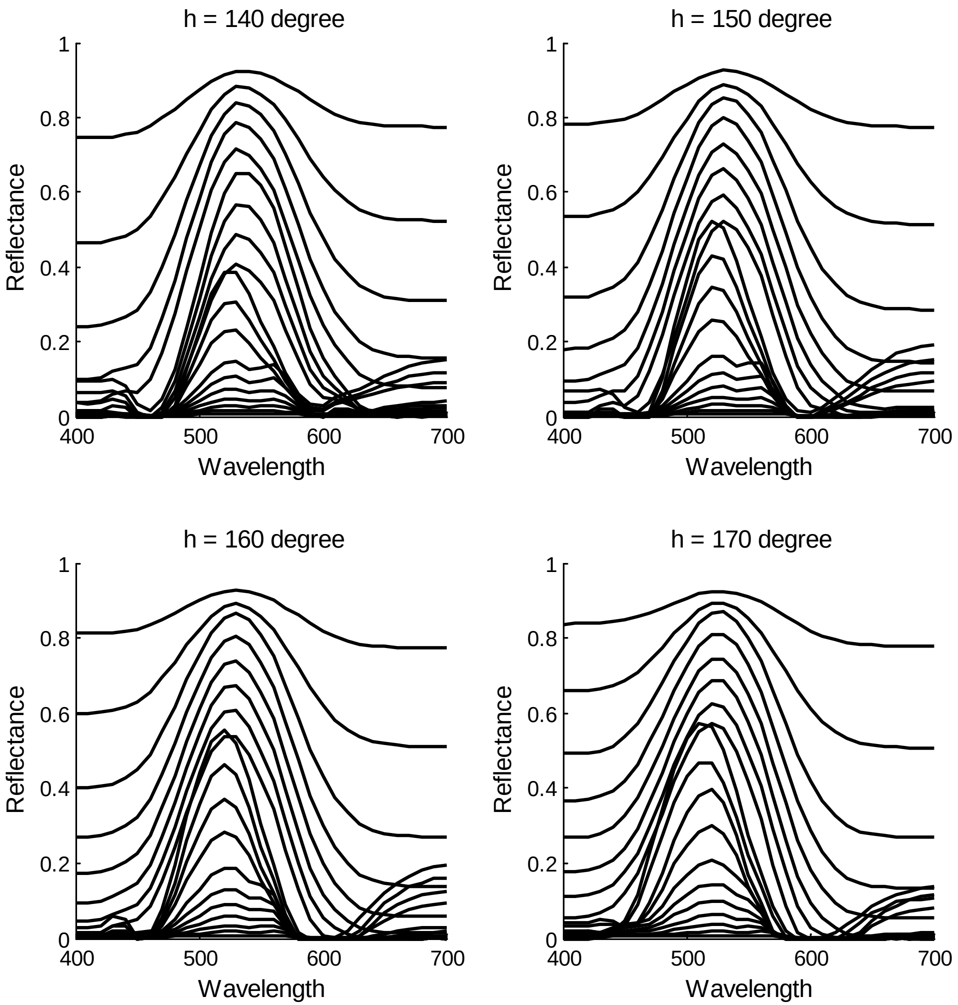
The Spectral Gamut



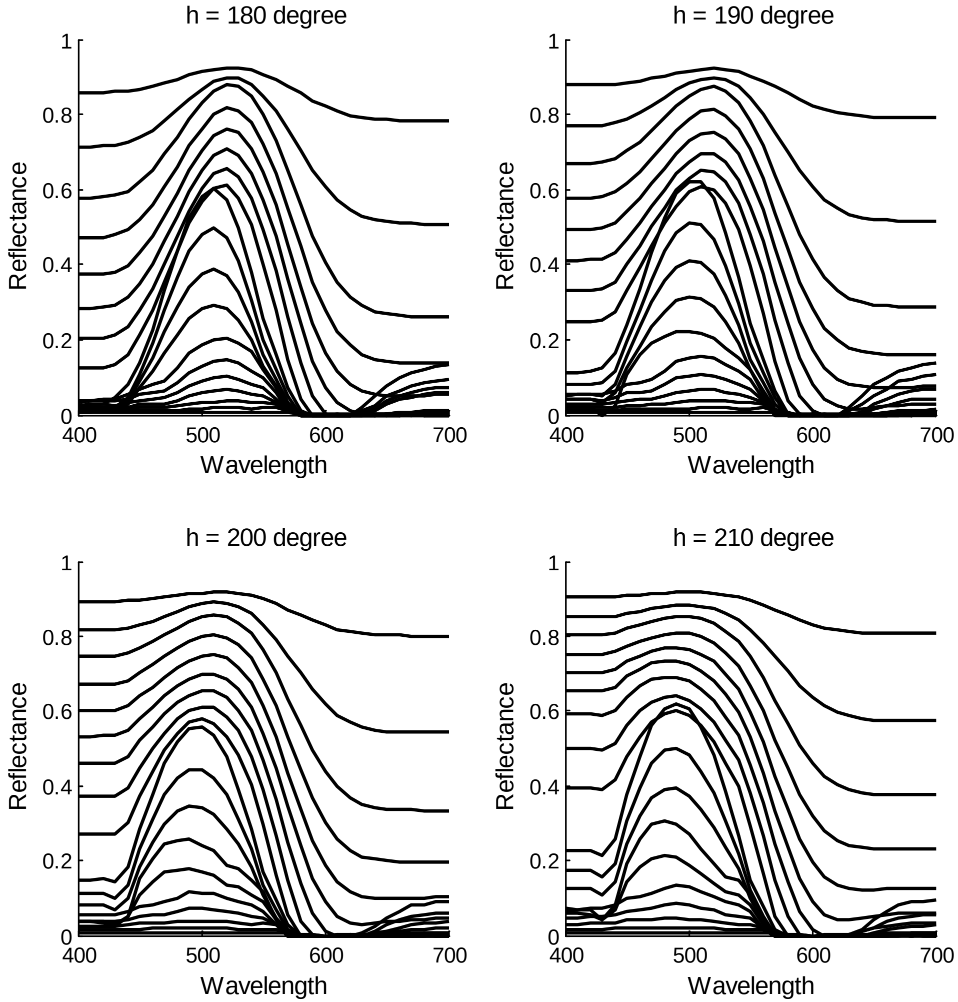
The Spectral Gamut



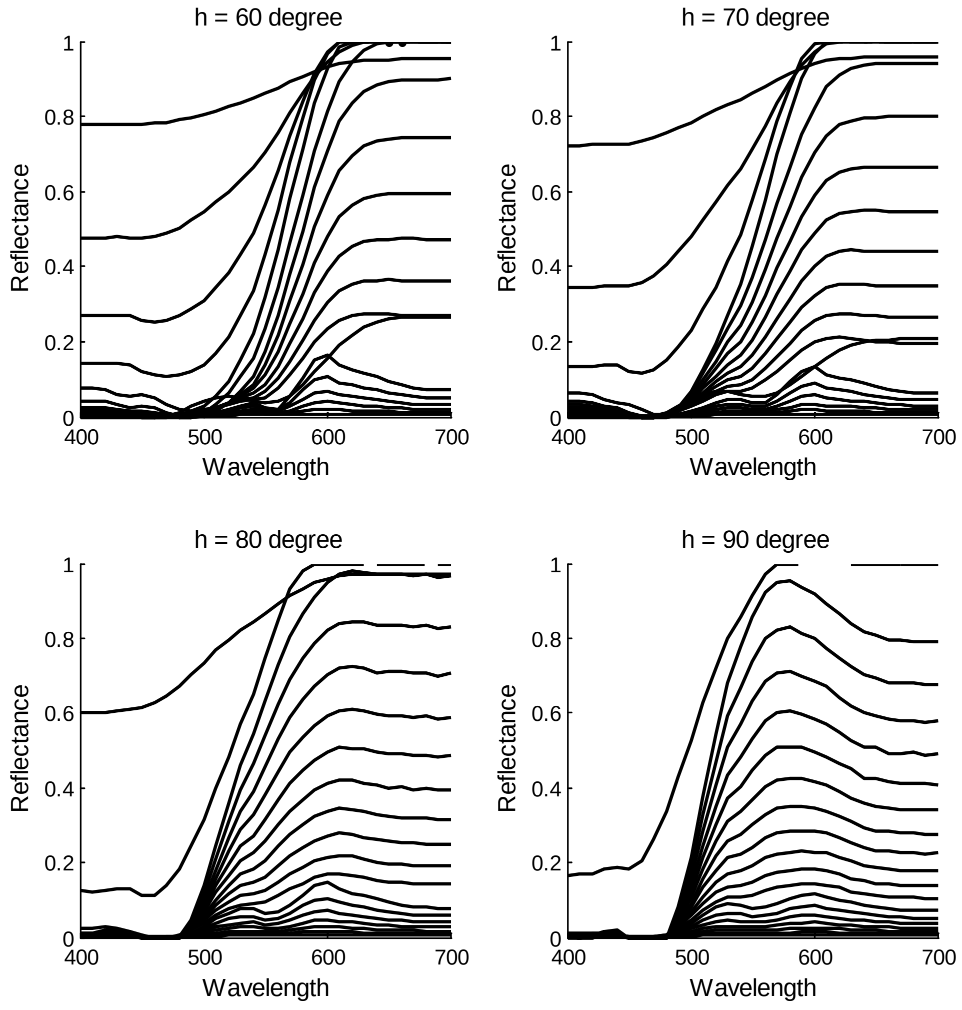
The Spectral Gamut



The Spectral Gamut



The Spectral Gamut



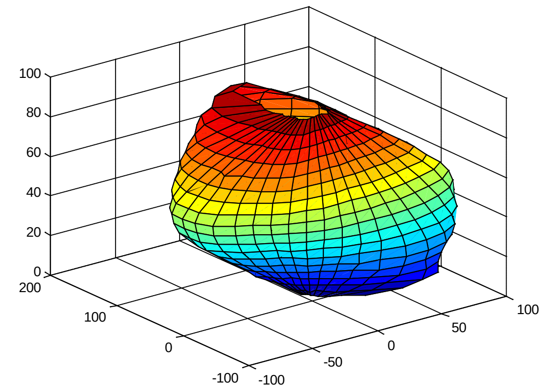
Applications

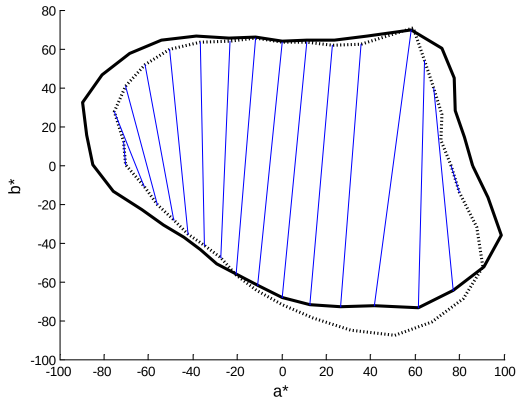
Colour gamut of real surface colours at any illuminant and observer combination (definitely)

Colour rendering index (need further work)

Volume shared volume, and shared area

Reflectance functions can also be used for computing CIE colour rendering index (CRI)





Device Characterisations (need further work)