別紙４（課程博士）

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Department 情報・知能工学専攻	Student ID Number 学籍番号	第 105310 号
Applicant's name 氏名	佐藤　智治	

Supervisors 指導教員	中内　茂樹 北崎　充晃

Abstract

論文内容の要旨　(博士)

Title of Thesis 博士学位論文名	視覚系における色情報表現とそのタスク依存性に関する研究 (Color Information Representation in the Visual System and Its Task Dependency)

(Approx. 800 words)

(要旨　1,200 字程度)

ヒトの視覚系はあらゆる視覚情報をいくつかの特徴に分け、それらを統合するという処理を行っている。色情報は視覚系が処理する情報の一つであり、検出や形状抽出、同定など基礎的な役割を持っている。ヒトの色覚メカニズムに関する多くの研究によって、網膜上の波長感度特性が異なる3種類の錐体細胞の応答信号が、反対色表現へと変換されるという、視覚系における色情報処理の流れが明らかにされてきた。色情報はさらに変化し、視覚皮質において反対色以外の色相に選択的に応答するニューロンや、特定の色度に応答するニューロンが生理学的な研究によって発見されている。心理物理学的にもさまざまな実験刺激や被験者の知覚判断が研究され、反対色表現だけでは説明できない結果が得られている。心理物理学的なデータを基に反対色以降の色情報表現の色相の数や組み合わせといった詳細が推定されているが、その結果は研究グループ間で一致しない。従って、反対色以降の色情報表現が行動的にどのような役割をもっているかは未解明である。本論文では視覚系における色情報表現の変化を色相と彩度の観点から心理物理学的に論じたものである。

本論文ではまず、多色テクスチャにおける色知覚特性を説明するために必要な色相数を推定する手法を提案した。これまでの先行研究では主に色空間上で1次元分布するような刺激が使用されてきており、円分布のような2次元分布で定義された多色テクスチャはほとんど使用されていない。従って、多色ノイズによる色知覚への効果は十分に明らかにされているとはいえない。本論文では実験手法としてノイズ効果を詳細に調査可能なClassification Image (CI) 法を採用した。CI法によって得られた膨大なデータを色覚モデルの応答に変換し、被験者応答を再現するように色覚モデルのパラメータを推定した。モデル解析の結果、4つの色相、さらにいえば反対色表現の感度バランスを調整することで今回の実験結果を説明することができた。これは多色テクスチャを使用したいくつかの先行研究と一致する。

次に、色弁別と閾上色差判断が刺激強度に対して同一の応答関数によって説明可能か検証した。色情報表現は照明光の色や周辺刺激の状況など、環境の変化に対応するために順応という機能を持っている。例えば、照明光の彩度が高い場合、視覚系は完全に順応することができず、順応領域が色づいてみえる。本論文ではこのような不完全色順応状態における色弁別と閾上色差を比較した。結果として、遂行するタスクによって感度が最適化されている「均衡点」が異なることがわかった。これは色弁別と閾上色差判断の間に異なる色情報表現が介在することを示唆する。

以上、本論文では色情報表現の変化を明らかにするべく、CI法と色覚モデルに基づく解析を組み合わせた新たな解析手法を提案した。また、心理物理学的タスクによって異なる色情報表現が介在することを示した。本論文の成果によって、色情報表現に関する先行研究が整理され、色情報表現の変化の様相が明らかになっていくものと考える。

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Human visual system divides incoming visual information into some features and integrates them. Color information is one of these visual information. Previous works have revealed that color information representation in the visual system varies as color information processing proceeds. In the initial stage, colors are encoded as the responses of three different classes of cone photoreceptors. Next, these cone signals are combined and transformed to the responses of one luminance channel and two opponent color channels in the second stage. Color representation at the second stage is referred to as cone-opponent. After the second stage, color representations of cortical neurons are more complex. Physiological studies find that the cortical neurons selectively respond to various hues in addition to the opponent colors. Psychophysical studies also reported a phenomenon that could not be explained by the cone-opponent representation, using various stimuli and psychophysical tasks. Although the properties of the post cone-opponent representation, such as the number of hues, peaks, and bandwidths of channels, have been estimated in several different studies, the results have been somewhat inconsistent. Therefore, it is still unclear what is a role of the post cone-opponent color representation. This thesis, therefore, aims to investigate the role of the transformation of color information representation in aspects of hue and saturation.

First, this thesis examined effects of heterochromatic noise on chromatic contrast perception. The Classification Image (CI) technique that enables us to investigate the effect of random chromatic noise on color perception was applied. The stimulus was a superposition image of two uniformly colored squares (signal images) and a multicolored texture (a noise image), whose colors were chosen out of an isoluminant plane in the Derrington-Krauskopf-Lennie (DKL) color space. The observers judged the relative chromatic contrasts of the two signal squares on the different noise textures. CI showed strong color modulations, whose color directions differed from the signal. Moreover, instead of a typical CI analysis procedure, the CI data were analyzed based on chromatic mechanism models to estimate the details of the mechanisms. The model was composed of several chromatic mechanisms tuned to different hues. Several chromatic mechanisms which effectively explained the combinations of the stimulus colors and an individual observer's responses were selected out of the candidates of the mechanisms with the stepwise procedure; the response weights of the selected mechanisms were adjusted with the logistic analysis so that their responses fit the observers' responses. The analysis results showed that the model with only four mechanisms, including the cardinal models, was superior to the model composed of more mechanisms for explaining our results.

Next, this thesis discussed that a common response function could be responsible to perception of saturation in different psychophysical tasks: color discrimination and supra-threshold color difference (STCD) judgment. Both of color appearances and color discrimination performances are influenced by spatial context such as color of

illumination or a color of uniform surround/pedestal. The adjustment of sensitivity accompanied by the changes in the context is referred as adaptation, and it enables us to maintain the color appearance or discrimination performance under various environments. However, incomplete chromatic adaptation has been reported in several studies on color appearance, where an adaptation color is too saturated to adapt it completely. In this case, color discrimination and STCD under the complete chromatic adaptation (Gray) and the incomplete chromatic adaptation condition (Red) were measured. The color-difference profiles were examined by evaluating the perceptual distances between various color pairs using the maximum likelihood difference scaling method. After that, sensitivity functions were derived from the responses of two tasks to test whether a common sensitivity function was responsible for both the tasks. In the Gray condition, the chromaticities corresponding to the smallest threshold and the largest color difference were almost identical. In contrast, in the Red condition, they were dissociated. The results obtained in the incomplete chromatic adaptation condition revealed the presence of at least two peaks. The primary peak location clearly differed between the two tasks, suggesting that different color representations or mechanisms were involved in the two tasks.

In summary, this thesis developed a novel method that combined the CI method with chromatic mechanisms models to estimate a detail of the color information representation in the visual system. This thesis also revealed distinct color information representations in the visual system which are responsible for color discrimination and STCD tasks. These findings allow us to organize the various aspects of the color information representation in the visual system which have been argued in the previous studies.